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WEAPON SIMULATOR TEST METHODOLOGY INVESTIGATION: COMPARISON OF LIVE FIRE AND WEAPON SIMULATOR TEST METHODOLOGIES AND THE EFFECTS OF CLOTHING AND INDIVIDUAL EQUIPMENT ON MARKSMANSHIP

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14. ABSTRACT:

A novel weapon simulator test methodology has been developed for evaluating the effect of Clothing and Individual Equipment (CIE) on marksmanship performance, without the additional cost, safety, and logistical concerns associated with live fire evaluations. The purpose of the evaluation documented in this report was to determine if the weapon simulator test methodology detected the same effects of CIE on marksmanship performance as seen on the live fire range by comparing the data collected using the same Test Participants (TPs) in both the live fire and simulated conditions.

Eleven military TPs with marksmanship experience executed the live fire and simulator test methodologies in both a baseline configuration and in a test configuration which included the M40 Chemical-Biological (CB) protective mask. Marksmanship performance dependent variables analyzed included shot group tightness, radial error from the center of the target, and multiple time variables.

The weapon simulator and live fire test methodologies were both able to capture similar trends regarding the impact of the M40 Mask on marksmanship performance. There were no significant differences between the No Mask and M40 Mask configurations in terms of shot accuracy in either the live fire or weapon simulator results, and both test methodologies also found significant main effects for firing position. The main difference in the results was that the weapon simulator results revealed a significant difference in time to transition between targets, whereas no significant differences in engagement time were found in the live fire results.

15. SUBJECT TERMS

AIMING	VARIABLES	BALLISTIC TESTS	PROTECTIVE MASKS	TEST AND EVALUATION
METRICS	M-40 MASKS	MARKSMANSHIP	RANGES(FACILITIES)	M4O PROTECTIVE MASK
TARGETS	SIMULATION	SHOT ACCURACY	MILITARY TRAINING	PERFORMANCE(HUMAN)
WEAPONS	SIMULATORS	ARMY PERSONNEL	POSITION(LOCATION)	TARGET TRANSITIONING
LIVE FIRE	PROFICIENCY	LIVE FIRE TESTING	TEST METHODOLOGY	FIRING TESTS(ORDNANCE)
ACCURACY	MEASUREMENT	HUMAN FACTORS	PERFORMANCE TESTS	SHOOTING PERFORMANCE
BASE LINES	REACTION TIME	DATA COLLECTION	CIE(CLOTHING AND INDIVIDUAL EQUIPMENT)	

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Executive Summary

Introduction

Efforts are underway by the Natick Soldier Research, Development, and Engineering Center (NSRDEC) Human Factors (HF) team to develop a standardized test methodology utilizing a Noptel MilTrainer weapon firing simulator to assess weapon compatibility when impacted by Clothing and Individual Equipment (CIE). Work for this project was performed from October 2014 to August 2015.

The simulator test methodology described in this report is not intended to replace live fire evaluations, but the use of a weapon simulator has some advantages over live fire evaluations, particularly for early evaluations of developmental items. The advantage of simulator research, provided it accurately represents real-world performance, is that it can collect similar information regarding the impact of CIE on marksmanship performance without the costs and the safety concerns that can be associated with live fire testing.

The purpose of the evaluation documented in this report was to determine if the weapon simulator test methodology detected the same effects of CIE on marksmanship performance as seen on the live fire range by comparing the data collected using the same Test Participants (TPs) in both the live fire and simulated conditions.

In order to compare the simulator test methodology to live fire, an evaluation was conducted where TPs executed the live fire and simulator test methodologies in a baseline configuration and in a test configuration which included the M40 Chemical-Biological (CB) protective mask.

The Army Research Laboratory – Human Research and Engineering Directorate (ARL-HRED) Dismounted Warrior Branch conducted the live fire trials at their M-range target shooting facility to provide quantitative measures for comparison. The live fire test methodology represented a typical evaluation which would be conducted by ARL-HRED to evaluate the effect of CIE on marksmanship.

If the same trends were observed in each of the test methodologies (particularly in terms of significant differences between the M40 Mask and No Mask configurations) it would suggest that the weapon simulator test methodology is representative of performance on a live fire range and can be used to collect useful information regarding the effect of CIE on marksmanship.

A total of nine Active Duty Soldiers from the 75th Ranger Regiment and two Aberdeen Test Center (ATC) Contractors as Representative Soldiers (CARS) served as TPs in the evaluation, which took place at Aberdeen Proving Ground, Aberdeen, MD in October 2014.

Two different equipment configurations were used in this evaluation: a baseline configuration (without the M40 CB mask) and a test configuration (including the M40 CB mask). All configurations included a helmet, plate carrier body armor, and a combat load of ancillary pouches. The only difference between the baseline and test configurations was the addition of the M40 CB mask.

Methods

For the live fire test methodology, the TPs completed six conditions based on equipment worn and firing position (three No Mask conditions and three M40 Mask conditions).

- Standing Unsupported without M40 CB mask
- Kneeling Unsupported without M40 CB mask
- Prone Unsupported without M40 CB mask
- Standing Unsupported with M40 CB mask
- Kneeling Unsupported with M40 CB mask
- Prone Unsupported with M40 CB mask

Independent variables included mask condition, range to target, and accommodation time. Target ranges were 100, 150, and 200 m. Exposure time (i.e., the time the target was exposed for sighting acquisition) was set at 4 s. Time between targets was 2 s. Dependent variables analyzed were hit percentage, radial error from the center of the target, and response time.

In addition to the standard live fire test methodology, a stationary 75 m target was added. This target required each participant to shoot two series of five shots in the following conditions (this target mimicked one of the simulated shooting tasks, and therefore allowed for a direct comparison between live fire performance and weapon simulator performance):

- Standing Unsupported without a mask
- Kneeling Unsupported without a mask
- Prone Unsupported without a mask

For the weapon simulator test methodology the TPs completed 14 conditions based on equipment worn and firing position (7 No Mask and 7 M40 Mask configurations).

- Without M40 CB Mask
    - One Target: Standing Unsupported
    - One Target: Kneeling Unsupported
    - One Target: Prone Unsupported
    - Five Targets: Standing Unsupported – Center, Left, Right Movement
    - Five Targets: Standing Unsupported – Center, Right, Left Movement
    - Five Targets: Kneeling Unsupported – Center, Left, Right Movement
    - Five Targets: Kneeling Unsupported – Center, Right, Left Movement
- With M40 CB Mask
    - One Target: Standing Unsupported
    - One Target: Kneeling Unsupported
    - One Target: Prone Unsupported
    - Five Targets: Standing Unsupported – Center, Left, Right Movement
    - Five Targets: Standing Unsupported – Center, Right, Left Movement
    - Five Targets: Kneeling Unsupported – Center, Left, Right Movement
    - Five Targets: Kneeling Unsupported – Center, Right, Left Movement

Dependent variables analyzed on the weapon simulator were shot group tightness (E-Distance), distance of shots from the center of the target (B-Distance), total time between shots, aiming time, and movement time.

Results and Conclusions

The weapon simulator and live fire test methodologies were both able to capture similar trends regarding the impact of the M40 Mask on marksmanship performance.

Both the live fire and weapon simulator results found that, in terms of shot accuracy, TPs performed slightly better in the No Mask configuration than in the M40 Mask configuration, but these differences were not statistically significant.

Both test methodologies also found significant main effects for firing position. During the live fire testing, the Prone Unsupported firing position yielded a significantly higher hit rate than the Standing or Kneeling Unsupported firing positions. A general trend was observed in which the TPs became progressively more accurate in the Standing, Kneeling, and Prone Unsupported firing positions. These same trends were observed on the weapon simulator, with statistically significant differences in B-Distance and E-Distance found between firing positions.

In terms of evaluating the effect of equipment on marksmanship performance, the main difference that was observed was that the weapon simulator results revealed a significant difference in time to transition between targets. In the live fire results, no significant differences in engagement time were found. This is believed to be due to the difference in movement angle between the weapon simulator test methodology and the live fire range, rather than being an inherent difference in performance with a weapon simulator. This finding is in line with one of the advantages of a weapon simulator, which is that the simulator has more flexibility regarding target locations. The simulator can therefore stress equipment to a greater extent, such as achieving greater distances/angles between targets. If the live fire range presented targets placed at greater angles relative to the shooter, it is believed the same results would be observed (i.e., it would take significantly longer to locate and engage a target in the M40 Mask configuration than in the No Mask configuration).

The results of the 75 m stand-alone target indicate that marksmanship performance on a weapon simulator may not be identical to the performance on the live fire range; the TPs performed significantly better on the weapon simulator than on the live fire range. However, both the weapon simulator and the live fire range data showed the same trends. For example, in the Standing Unsupported firing position, TPs performed significantly better with the weapon simulator than on the live fire range, but in both the live fire condition and the simulated condition, Standing Unsupported was significantly larger than the Kneeling and Prone Unsupported firing positions in terms of E-Distance.

The noted similarities in trends indicate that the weapon simulator test methodology outlined in the report can effectively be used to evaluate equipment, and that the results of the weapon simulator (as it relates to the effects of the M40 CB mask on marksmanship performance) mirror those which would be captured in a live fire evaluation.

WEAPON SIMULATOR TEST METHODOLOGY INVESTIGATION: COMPARISON OF LIVE FIRE AND WEAPON SIMULATOR TEST METHODOLOGIES AND THE EFFECTS OF CLOTHING AND INDIVIDUAL EQUIPMENT ON MARKSMANSHIP

1. Introduction

Efforts are underway by the Natick Soldier Research, Development, and Engineering Center (NSRDEC) Human Factors (HF) team to develop a standardized, validated test methodology utilizing a simple weapon firing simulator to assess weapon compatibility when impacted by Clothing and Individual Equipment (CIE). These efforts support NSRDEC Proposal 13-137: Development of a Novel Human Performance Test Methodology to Assess the Impact of Clothing and Individual Equipment on Weapon Firing Accuracy. Work for this project was performed from October 2014 to August 2015.

NSRDEC's Human Systems Integration Laboratory allows for the early, comprehensive evaluation of preliminary concepts, prototypes, and developmental CIE by employing the knowledge of HF Subject Matter Experts and proven tools/techniques to evaluate various HF attributes associated with Warfighter-borne gear/equipment. Some of the common HF attributes assessed are ease of use, overall acceptability to the Soldier for performing their mission, and the compatibility/interoperability of all the gear/equipment Soldiers currently wear when in an operational environment. One of the most important compatibility/interface issues for any item of CIE is a Soldier's ability to accurately engage targets with their primary weapons system.

Currently, weapons compatibility is assessed primarily in two ways: subjective assessment using mock weapons or live fire testing. Weapon simulator systems also exist which can be used to assess weapon compatibility, but these are typically large, permanent structures (i.e., the Engagement Skills Trainer (EST) 2000) which are not portable and which require extended training time prior to data collection activities. There is a need for a more objective, quantitative measure to determine weapons compatibility/interoperability with CIE, without the additional costs and safety concerns associated with live fire testing, and with the capability of being utilized in both laboratory and field environments.

A system and test procedure capable of obtaining operationally relevant, measurable data will assist in the identification of restrictions encountered when performing tasks associated with target acquisition. By employing these techniques at early stages of development, design issues that contribute to restrictions in performance can be isolated and solutions to alleviate those deficiencies can be developed. The developed test methodology, using a Noptel MilTrainer weapon simulator system, provides the NSRDEC HF team with an easily transported system that can be used to collect quantitative data regarding compatibility between weapons and CIE, and the effect of CIE on marksmanship performance.

The purpose of the evaluation detailed in this report was to determine if differences in target engagement times and/or accuracy due to the impact of the M40 Chemical-Biological (CB) protective mask are identified in both the weapon simulator test methodology and in a live fire test methodology.

The simulator test methodology described in this report is not intended to replace live fire evaluations, but it has some advantages over live fire shooting, particularly for early evaluations of developmental items. The advantage of simulator research, provided it accurately represents real-world performance, is that it can collect similar information regarding the impact of CIE on marksmanship performance without the costs (i.e., specialized facilities, range-control personnel, ammunition, etc.) and the safety concerns (i.e., a simulator has more flexibility regarding target locations, target spread, high angle targets, etc. because there are no range restrictions) that can be associated with live fire testing. Some disadvantages of simulator testing include a lower force of recoil than is experienced by the shooter when shooting live rounds, and that it typically does not take outdoor atmospheric conditions into account.

A fairly extensive set of studies on weapon simulator systems currently exist, which indicate that performance using a weapon simulator system (particularly the EST 2000 and Laser Marksmanship Training System (LMTS)) is predictive of live fire qualification scores using M4/M16 series weapon systems (Crowley et. al., 2014; Hagman, 2000; Schendel et. al., 1985; Torre et. al., 1987). Additionally, Scribner et. al. (2007) found a strong relationship between live fire performance and performance using the DISALT weapon simulator, although radial error (distance of shots from the center of the target) was significantly lower for the simulator condition, indicating test participants (TPs) were more accurate when using the simulator than when firing live rounds.

In order to compare the methodologies, an evaluation was conducted at Aberdeen Proving Ground (APG), Aberdeen, MD in October 2014, where TPs executed the live fire and simulator test methodologies in a test configuration (which included the M40 CB protective mask) and in a baseline configuration (no M40 CB mask). It was hypothesized that the addition of the M40 mask would negatively affect marksmanship performance, and therefore its effect on performance could be analyzed to determine if the weapon simulator data aligns with live fire data (i.e., if similar performance decrements appear in the results of both test methodologies).

The Army Research Laboratory – Human Research and Engineering Directorate (ARL-HRED) Dismounted Warrior Branch conducted the live fire trials at the M-range target shooting facility to provide quantitative measures for comparison. The value of live fire shooting is to provide realistic and objective analyses under realistic conditions. The advantages to live fire research are the ability to identify critical performance issues, combat effectiveness, and survivability, and to enable corrections before items are fielded. Live fire shooting also offers outdoor atmospheric conditions such as changing wind velocities, barometric pressures, and ambient conditions.

One difficulty in comparing the two test methodologies is that the targets differed in relative angle and range from the shooter. As described in Section 2.5.2, the weapon simulator methodology used both One Target and Five Target scenarios and all of the targets were scaled to represent a full-size E-type silhouette at 75 m.

For the One Target scenario, the target is placed directly in front of the shooter, 1.57 m off the ground, which is between shoulder and eye height for most of the male Army population[1]. On

[1] 1.57 m is 15th percentile of male Eye Height Standing, 98th percentile of male Suprasternale Height and Acromial Height, (ANSUR, 2012)

this single target the TPs are asked to fire five series of five shots without time pressure in three firing positions (Standing, Kneeling, and Prone – all Unsupported). This allows the TPs to focus on proper shooting mechanics and be as accurate as possible, and allows for the evaluation of the effect of the equipment on slow aimed fire.

For the Five Target scenario, three of the targets are 1.57 m off the ground and off-set from each other by 50°, with two high angle targets (2.77 m off the ground) placed directly above the right and left targets. These target locations were selected specifically with the evaluation of CIE in mind. The testers wanted to force the TPs to turn their entire body to effectively engage the left/right targets. It was also hypothesized that engaging targets at high angles relative to the shooter could uncover potential restrictions from CIE. Additionally, the Five Target scenario introduces time pressure, as the TPs are now asked to engage the targets as quickly as possible, without sacrificing accuracy.

The goal of this effort was to evaluate the efficacy of the weapon simulator test methodology as currently defined, and the target locations are an integral piece of the test methodology. However, it was not possible to exactly replicate these target locations on the live fire range. The live fire range is limited to specific lanes/target locations. By utilizing all four lanes on M-Range (A-D lanes) it is possible to construct a live fire scenario with targets placed at angles up to 110° relative to the shooter (see Figure 1). However, such a scenario is limited by the existing locations of the target berms/bunkers, and it was not possible to place targets at exactly 50° relative to the shooter and at a 75 m engagement distance. Also, due to safety considerations, high angle targets are not supported at M-range (without a backstop the round would continue to travel for a great distance).

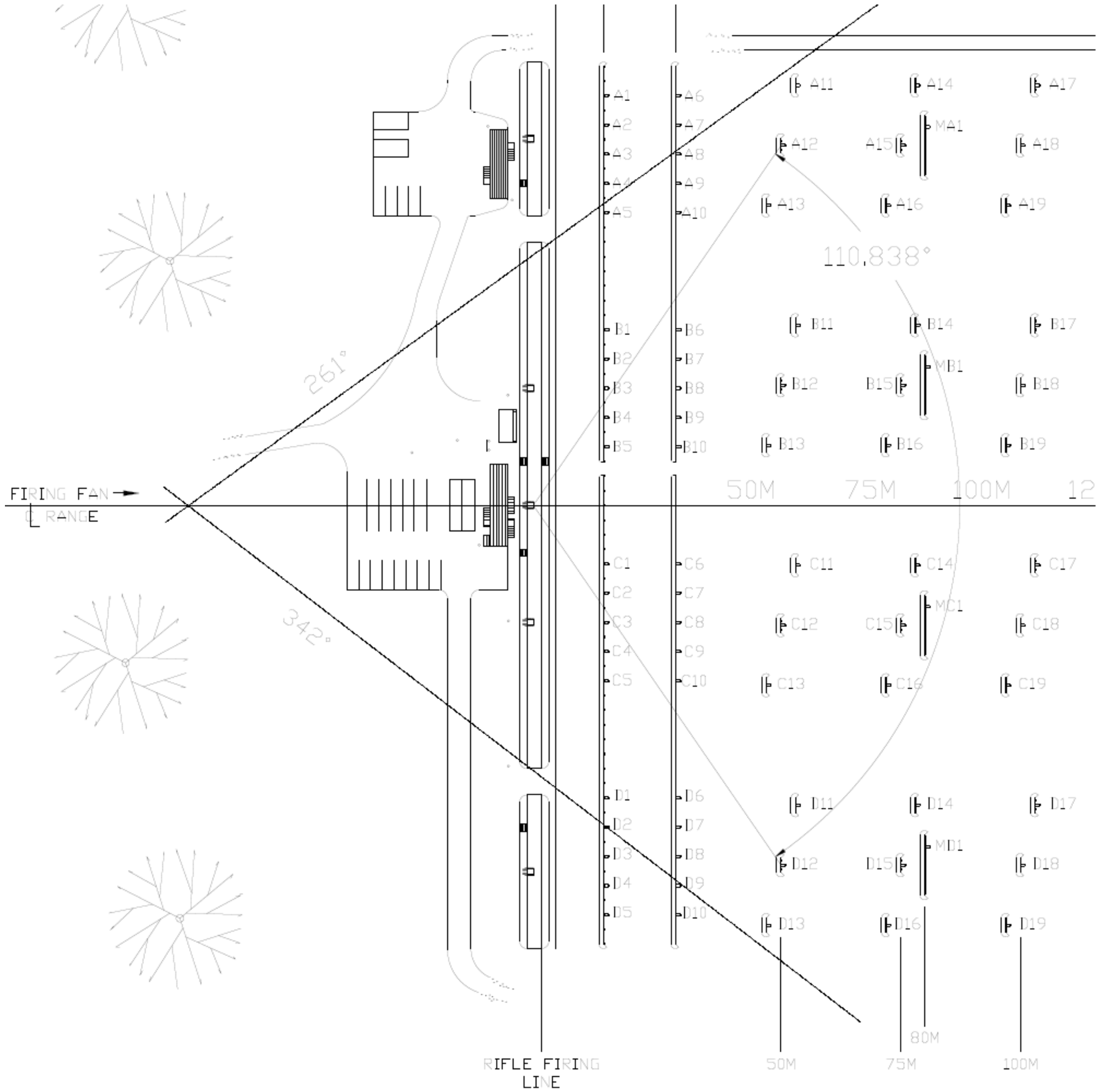

Figure 1. Schematic of M-Range at APG

To overcome these limitations, two courses of action were executed. One course of action was to set up a single E-type silhouette on the live fire range 75 m directly in front of the shooter. The TPs fired two series of five shots at this target in the Standing, Kneeling, and Prone Unsupported firing positions. This was executed as a side-bar task, and allowed for direct comparison between the performance on the live fire range and performance on the weapon simulator in the One Target scenario.

The other course of action was to conduct a live fire evaluation as it would normally be conducted by ARL-HRED if they were to evaluate the effect of an item of CIE on marksmanship. In order to evaluate the effect of the M40 mask on marksmanship/weapon compatibility they would typically conduct an evaluation as described in Section 2.5.1. Target ranges were 100, 150, and 200 m, with a 4.0 s exposure time, and 2.0 s between target presentations. The targets were also randomly presented over the center, left, and right berms relative to the shooter, and the TPs engaged the targets in the Standing Unsupported, Kneeling Unsupported, and Prone Unsupported firing positions.

Therefore, the live fire test methodology differed from the weapon simulator test methodology in that it included an additional independent variable (range) which was not part of the weapon simulator evaluation; the targets would randomly "pop-up" and required the TPs to locate the next target, acquire a sight picture, and fire at the target within 4 s; there was a forced 2 s delay in between target presentations; and the relative angle between the center, left, and right targets was much smaller than 50° (see Table 1).

Table 1. Relative Angle Between Target Locations on Live Fire Range (°)

Engagement Distance	Left to Center Berm	Center to Right Berm
100 m	6.8	7.2
150 m	4.6	4.8
200 m	3.5	3.6

These differences meant that the data between the live fire test methodology and the weapon simulator test methodology could not be directly compared; however, the results of each of the test methodologies could be analyzed to identify trends in results. If the same trends were observed in each of the test methodologies (particularly in terms of significant differences between M40 Mask and No Mask configurations) then it indicates that the weapon simulator test methodology is representative of performance on a live fire range and can be used to collect useful information regarding the effect of CIE on marksmanship. Alternatively, if the live fire results were drastically different from those seen with the weapon simulator, it would indicate that the weapon simulator test methodology is not a viable alternative for the evaluation of CIE.

2. Methods

2.1. Test Participants (TPs)

A total of 11 TPs were recruited to take part in this evaluation. Nine TPs were Active Duty Soldiers (MOS 11B). These were experienced Infantry Soldiers from the 75th Ranger Regiment who traveled to Aberdeen specifically to participate in this evaluation. Two TPs were Aberdeen Test Center (ATC) Contractors as Representative Soldiers (CARS). One of the CARS was an 11B in the US Army Reserves, and the other was a former Infantryman in the United States Marine Corps (USMC) and a competitive shooter.

All TPs were experienced military shooters, and ranged in age from 21 to 50 years old. (M = 26.54, SD = 8.37). All participants were male, and all except one had qualified within the last year using the M4 carbine. Ten of the TPs last qualified at the *Expert* level (score of 170–200 on the standard weapons qualification course), while one ATC CARS participant last qualified as a *Sharpshooter* 3 years earlier. All participants reported prior experience using a wide range of rifle optics. One of the 11 participants was left-handed and left-eye dominant.

TPs participated in the study during daylight hours from approximately 0800 to 1630. Data collection took place over an 8-d period with each Soldier actively shooting for 2 d.

A summary of the demographic data collected can be found in Appendix A.

2.2. Test Configurations

TPs executed the live fire and simulator test methodologies in a test configuration (which included the M40 CB protective mask) and in a baseline configuration (no M40 CB mask).

All TPs wore a helmet, a plate carrier body armor system, and a combat load of ancillary pouches. The helmet, body armor, and pouches were all provided by the TPs and represented the equipment they typically train with and wear in combat; therefore, there were some variations from individual to individual. However, the fighting load of ancillary pouches remained the same for an individual between the baseline configuration (No Mask) and the test configuration (including the M40 CB mask). The only difference between the baseline and test configurations was the addition of the M40 CB mask.

Each TP conducted the full set of experimental scenarios in both the Noptel weapon simulator and on the live fire range. The order of presentation was counterbalanced for methodology (live fire or simulator) and for configuration (M40 CB Mask or No Mask).

2.3. Preliminary Activities

Upon arrival, the TPs were given an orientation on the study's purpose and the details of their participation. They were briefed on the experimental objectives and procedures, informed how results would be used, and told what benefits the military can expect from this investigation. Any questions the participants had regarding the study were answered. The TPs were then asked to complete an Informed Consent Form. Its contents were explained verbally, and TPs were asked to read and sign the form if they decided to participate. The TPs were informed that they could withdraw from participation at any time without prejudice, although no TPs decided to withdraw over the course of this study. TPs were also asked for permission to photograph or videotape their experimental sessions.

After consent to participate in the evaluation was given, demographic and visual acuity data were recorded for each TP.

Visual acuity was measured for each TP using a Titmus vision testing apparatus. Corrected monocular visual acuities for both far and near distances were measured and recorded. Each TP had minimum correctable vision of 20/20 in one eye and 20/100 in the other eye, which is the current visual requirement for infantry. Four participants were aided by corrective contact lenses. Ocular dominance was determined using the sighting method. TPs were also asked their normal shooting eye and shooting handedness.

2.4. Evaluation Approach

2.4.1. Live Fire Evaluation Approach

For the live fire portion of the evaluation, the TPs completed a series of experimental scenarios on ARL HRED's M-Range. M Range is a live fire shooting range used to evaluate shooting performance of small arms systems (.50 caliber or smaller). It consists of four parallel firing lanes with target positions from 10 to 550 m on the two left lanes and targets from 10 m to 1000 m on the two right lanes. Figure 2 provides an aerial photograph of ARL HRED's M-Range. Target control is automated using customized computer algorithms, which enables the operator to program target presentation scenarios and to record live fire marksmanship data.

The target positions can support a variety of target types (e.g., E-type silhouettes (Figure 3), 3D IVAN targets, etc.), which are presented and retracted using pneumatically operated arms. Target control parameters include target sequence, range, presentation time, and duration, and may be varied to accommodate a broad selection of experimental scenarios. Accuracy and timing data are recorded using shot microphones placed at the shooter's position and behind each target. The supersonic projectile of each shot, whether firing in semiautomatic or full automatic mode, generates a shock wave which is detected by the microphones. Shock wave timing is used to triangulate shot location, accurate to within 5 mm, and is expressed as an x-y coordinate relative to the target plane. Shock waves from shots that miss the target by up to approximately 12 inches surrounding the target are also captured.

Figure 2. ARL HRED M-Range Shooting Performance Research Facility

Figure 3. Olive Drab "E" Type Silhouette Targets at M-Range

The TPs used the M4/M4A1 5.56 mm carbine (Figure 4) for the live fire evaluation. The M4/M4A1 is a lightweight, gas-operated, air-cooled, magazine-fed, selective-rate, shoulder-fired weapon with a collapsible polymer butt stock. A shortened variant of the M16A2 rifle, the M4 is equipped with a shorter barrel, collapsible stock, and optional accessory rails. The M4 provides shooters operating in close-quarters with improved handling and the capability to rapidly and accurately engage targets at extended ranges, day or night, with accurate, lethal fire.

Figure 4. M4/M4A1 5.56 mm Carbine

The TPs used the M150 Advanced Combat Optical Gunsight (ACOG) (Figure 5) in conjunction with the M4/M4A1 carbine for this evaluation. The M150 ACOG is a fixed 4x-magnified optic designed for the US Army's M4 weapon system. It incorporates dual illumination technology using a combination of fiber optics and self-luminous tritium.

Figure 5. M150 ACOG

2.4.1.1. Live Fire Experimental Conditions

There were six live fire conditions in this study. Three of these conditions required each participant to don an M40 CB mask. Three baseline conditions were included to examine the effects of practice, exposure time, and condition order on shooter performance. The following conditions were used in this study:

- Standing Unsupported – No Mask
- Kneeling Unsupported – No Mask
- Prone Unsupported – No Mask
- Standing Unsupported – M40 CB Mask
- Kneeling Unsupported – M40 CB mask
- Prone Unsupported – M40 CB mask

There was also a stationary 75 m target at which each TP was required to shoot two series of five shots in the following conditions:

- Standing Unsupported – No Mask
- Kneeling Unsupported – No Mask
- Prone Unsupported – No Mask

Independent variables included mask condition, range to target, and accommodation time. Target ranges were 100, 150, and 200 m. Exposure time (i.e., the time the target was exposed for sighting acquisition) was set at 4.0 s. Time between targets was 2 s.

2.4.1.2. Live Fire Range Familiarization

Once the TPs met the basic criteria to participate in this study, were briefed on the experimental procedure, and signed an informed consent form, they proceeded with range familiarization. They were thoroughly briefed on the conduct of the study, all standard operating procedures (SOPs), and safety requirements relative to the facility.

Shooters were shown a visual example of the aim point prior to initiating the trial, and were instructed to aim at the center of mass location of the target. They were scored on how close the round hit relative to that point and they were timed on how long it took them to fire each round.

2.4.1.3. Live Fire Training

Following range familiarization, shooters were issued the weapon they would be firing. Shooters then zeroed the ACOG sight that was mounted on the weapon according to zeroing procedures for the weapon. Shooters completed one familiarization trial in the standing and prone positions with and without the M40 CB mask. Each participant shot one 30-round magazine for each training condition.

2.4.1.4. Live Fire Testing Sequence

Soldiers fired in either the M40 CB Mask condition or the No Mask condition on the first day followed by the mask condition they did not complete on the second day. To account for practice and order effects, the shooter firing order for conditions was counterbalanced.

Following the three counterbalanced conditions on the first day, the 75 m stationary target condition was presented. The subject was not required to wear a mask for this condition. The subject was asked to complete two series of five shots each in the following positions: Standing Unsupported; Kneeling Unsupported; and Prone Unsupported.

20 targets were presented at each range in a random order for each trial. When the target was exposed, the Soldier engaged the target with a single shot. During the firing task, TPs fired from the firing position at targets at ranges of 100, 150, and 200 m with 10 targets appearing at each range for each trial. Targets had an exposure time of 4 s. Soldiers were told to aim at the marked center of mass location of the target, that they were scored on how close the round hit relative to that point, and that they were timed on how long it took them to fire each round. Figure 6 shows the different mask conditions and some of the different firing positions used in this study.

a) b)

Figure 6. (a) Soldier in the Standing Unsupported position wearing an M40 CB mask; (b) a Soldier in the Kneeling Unsupported position wearing an M40 CB mask

The Soldiers followed a counterbalanced order of presentation to complete all the conditions. The variables included:

- Independent variables
  - Mask condition
  - Range to target (100, 150, 200 m)
- Dependent variables
  - Shooting Accuracy, calculated by both hit percentage and radial error of misses from the center of the target
  - Shooting Response Time (RT; i.e., time to target engagement)

2.4.2. Noptel Weapon Simulator Evaluation Approach

For the weapon simulator portion of the evaluation, the TPs completed a series of experimental scenarios which were developed to evaluate the impact of CIE on marksmanship. A single set of experimental scenarios (Table 2) consisted of seven test conditions that varied in terms of firing position and number of targets. A total of 175 shots were fired in a complete Table of Fires.

A Noptel MilTrainer weapon simulator system was used to collect marksmanship performance data. The Noptel MilTrainer optical unit was mounted on the barrel of a de-militarized M4 carbine with an integrated CO_2 recoil simulation system (the de-militarized weapon and CO_2 system were manufactured by LaserShot, see Figure 7). The targets were paper ring targets scaled to represent a full-size E-Type Silhouette target at 75 m when placed 5 m away from the shooter (Figure 8).

The TPs also used the M150 ACOG sight for the weapon simulator portion of the evaluation, as they did in the live fire portion of the testing. After mounting the ACOG on the simulated weapon, the MilTrainer optical unit was adjusted to ensure the hit position recorded by the simulator was aligned with the settings of the ACOG.

a) b)

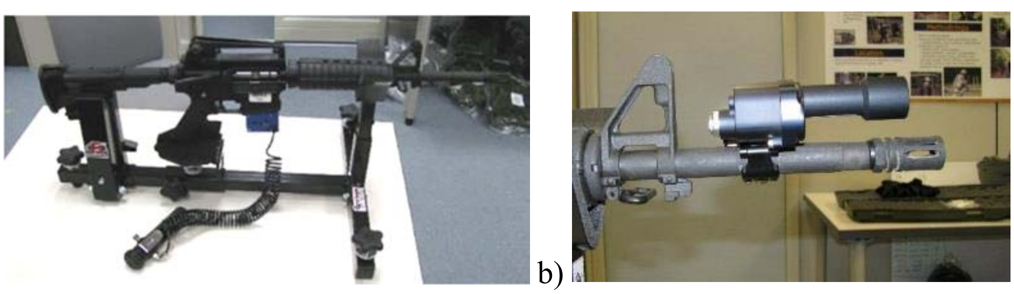

Figure 7. (a) The LaserShot weapon with integrated CO2 recoil simulator; (b) the Noptel MilTrainer optical unit mounted to the barrel of the weapon

Figure 8. The paper targets used for the weapon simulator

2.4.2.1. Weapon Simulator Practice/Qualification

TPs conducted the practice/qualification procedure while wearing only their Army Combat Uniform (ACUs). Each TP was initially asked to fire five shots at the center target. These shots were then used to “zero” the software to the particular shooter. Each TP was then asked to fire 10 shots at the center target in the Standing, Kneeling, and Prone Unsupported firing positions (10 shots in each firing position, a total of 30 shots).

- If 70% of the 10 shots were within the “6” ring (black area) of the target, the shooter is considered qualified for the Standing Unsupported firing position
- If 80% of the 10 shots were within the “6” ring (black area) of the target, the shooter is considered qualified for the Kneeling Unsupported firing position
- If 90% of the 10 shots were within the “6” ring (black area) of the target, the shooter is considered qualified for the Prone Unsupported firing position

Provided the shooter met the minimum qualification standards for each of the firing positions as outlined above, they then began the evaluation. If the shooter did not meet these minimum qualification standards, they were given additional practice until they were able to meet these standards.

2.4.2.2. Weapon Simulator Test Activities

After completing the preliminary activities, each TP proceeded into the firing activities. They completed the entire Table of Fires (all seven firing conditions, as listed in Table 2) in both the No Mask configuration and in the M40 CB Mask configuration.

The test configurations were assigned according to a counterbalanced schedule so that a different condition was worn first and second by each TP. The schedule was also based on whether the TP started with the simulator or on the live fire range.

Once assigned the first condition (No Mask or M40 CB Mask), the TP executed the One Target (center target) firing sequence, in the order presented in Table 2 (Standing, then Kneeling, then Prone), firing five series of five shots in each firing position.

The TP then continued into the Five Target firing sequence while standing. While executing this sequence, the TP was instructed to move from one target to another as quickly as possible without sacrificing accuracy. Once a shot was fired at one target, the TP moved to the next target in the sequence and fired another shot, and continued until he or she had completed a total of five shots (one at each target) while moving in either a right-to-left or left-to-right arc. The TP then repeated the series in the opposite direction/arc while standing. Finally, the TP knelt and repeated the Five Target sequence twice (once right-to-left and once left-to-right). The order of presentation of the Five Target sequence was also counterbalanced.

This process (completing every condition within the firing table) comprised one set of data for one configuration. This process was repeated until every One and Five Target sequence was executed in both the baseline and test configurations.

The experimental scenarios vary by number of targets and shooting position as follows:

Table 2. Summary of Table of Fires (all conditions)

Table of Fire		No. Targets	Firing Position	Order of Targets Engaged	No. of Series	No. Shots per Series	Total No. Shots
I	A.	1	SU	Center Only	5	5	25
	B.	1	KU	Center Only	5	5	25
	C.	1	PU	Center Only	5	5	25
II	A.	5	SU	C => R_{low} => R_{high} => L_{low} => L_{high}	5	5	25
	B.	5	SU	C => L_{low} => L_{high} => R_{low} => R_{high}	5	5	25
	C.	5	KU	C => R_{low} => R_{high} => L_{low} => L_{high}	5	5	25
	D.	5	KU	C => L_{low} => L_{high} => R_{low} => R_{high}	5	5	25

Note: SU = Standing Unsupported; KU = Kneeling Unsupported; PU = Prone Unsupported

Figures 9 and 10 show the target set-up (distances and heights) used in the One Target and Five Target scenarios.

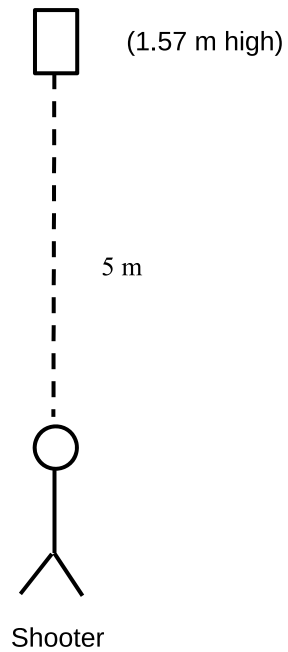

Figure 9. One Target – Center Front

The TPs fired a total of 75 shots for record in the One Target scenario, in three different firing positions, as described below:

- Standing Unsupported
  - Five (5) series of five (5) shots (25 total shots)
- Kneeling Unsupported
  - Five (5) series of five (5) shots (25 total shots)
- Prone Unsupported
  - Five (5) series of five (5) shots (25 total shots)

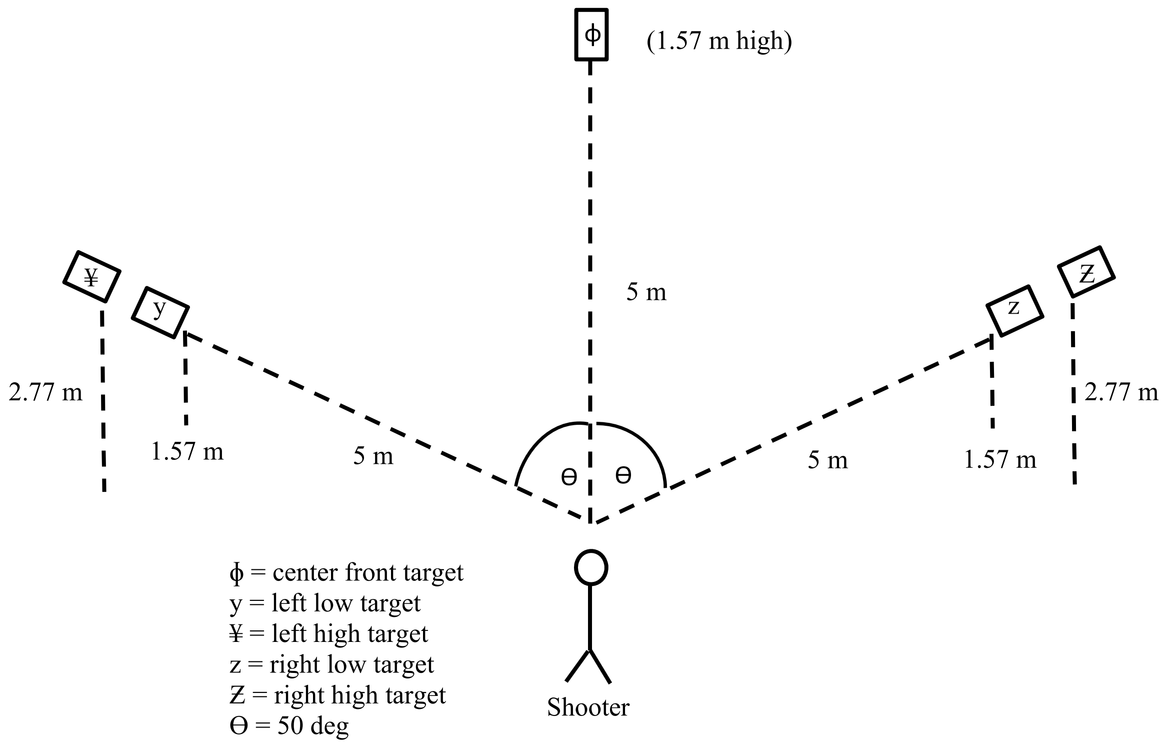

Figure 10. Five Target Set-Up

The TPs fired a total of 100 shots for record in the Five Target scenario, in two different firing positions, as described below:

- Standing Unsupported
  - Center Target => Left Low Target => Left High Target => Right Low Target => Right High Target
    - Five (5) series of five (5) shots (1 shot per target, 25 total shots)
  - Center Target => Right Low Target => Right High Target => Left Low Target => Left High Target
    - Five (5) series of five (5) shots (1 shot per target, 25 total shots)
- Kneeling Unsupported
  - Center Target => Left Low Target => Left High Target => Right Low Target => Right High Target
    - Five (5) series of five (5) shots (1 shot per target, 25 total shots)
  - Center Target => Right Low Target => Right High Target => Left Low Target => Left High Target
    - Five (5) series of five (5) shots (1 shot per target, 25 total shots)

After completing all shots in a given firing position, the TPs were asked to rate the degree of Interference/Degradation they experienced from the equipment while performing that task using the 5-point rating scale presented in Table 3.

Table 3. Subjective Rating Scale				
No Interference or degradation	Slight Interference; easily worked around	Moderate interference; difficult, but able to work around	Severe interference; very difficult to work around; unacceptable	Extreme interference; unable to work around; unacceptable
1	2	3	4	5

2.5. Data Analysis and Reporting

2.5.1. Live Fire Data Analysis and Reporting

The data for the 75 m stationary target and the 100, 150, and 200 m pop-up targets were analyzed separately. The data recorded from these shooting tasks were considerably different specifically for target exposure times and firing methods. Descriptive statistics on the dependent measures of hit time, radial error, and time to shot were calculated for each condition. Separate, independent three-factor {3 (body position) x 2 (mask condition) x 3 (range to target)}, within-subject analyses were conducted on the dependent measures of hit time, radial error, and time to shot. If significant main effects were found, Tukey's Honest Significant Difference (HSD) post-hoc tests were conducted to determine which conditions were significantly different from each other.

2.5.2. Weapon Simulator Data Analysis and Reporting

The Noptel NOS4 software records shot performance data real-time and presents multiple statistical calculations as well as individual shot scores and time between shots. In addition, the Noptel data were exported to Microsoft Excel and IBM's Statistical Package for the Social Sciences (SPSS) (IBM, 2011). Excel and/or SPSS were used to perform data reduction and analyses on the response data and to create table and chart summaries of the results.

Shooting performance was assessed with two variables generated from the Noptel system data – the E-distance and the B-distance.

The E-distance, or variable error (VE) (Schmidt, R. A. & Lee, T. D., 1999), measures the inconsistency (or consistency) in the outcome. This measurement is the averaged Euclidian distance[2] from the center of the shot series to each shot. If VE is small, the outcomes are consistent and located together closely. Another way to envision VE is "shot cluster size" or how tightly grouped the five shots in a shot series are (Figure 11).

The B-distance, or total variability (TV) (Schmidt, R. A. & Lee, T. D., 1999), measures how accurately the TPs performed. This measurement is the averaged Euclidian distance of the five-shot series to the bull's-eye (Figure 11). If the shot outcomes are close to the center of the target, TV is small. In other words, this variable is "shot accuracy".

[2] Euclidian distance is the distance between two points in a plane. For two points with coordinates (x, y) and (a, b), the distance is calculated by the formula: distance((x, y), (a, b)) = $\sqrt{(x-a)^2+(y-b)^2}$

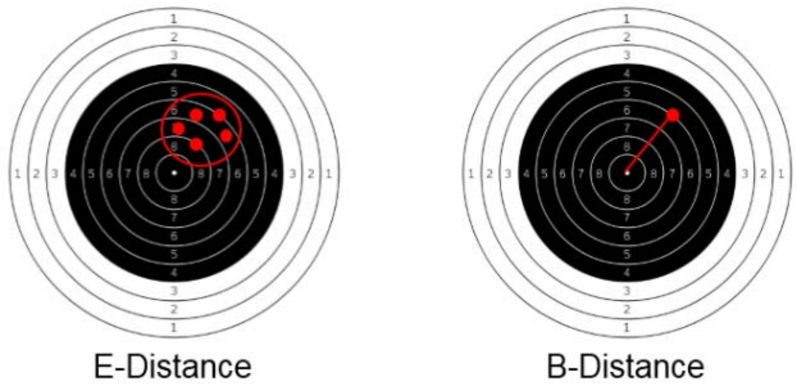

Figure 11. Visual example of E-Distance and B-Distance

For the Five Target scenarios, three time variables were analyzed in addition to E-Distance and B-Distance.

The total time between shots (Total Time) is calculated from time-stamps automatically recorded by the Noptel software.

Aiming Time is a second variable automatically recorded by the Noptel software. Aiming time represents the time a TP spends aiming at the target prior to firing (time starts when the system detects that the weapon is aimed at the target).

Movement Time is calculated by subtracting the Aiming Time from the Total Time, and represents the time spent transitioning from one target to the next.

The dependent variables for the sensitivity analysis (VE, TV, Total Time, Aiming Time, and Movement Time) were statistically compared across the test conditions to determine whether any performance differences in these variables existed across body armor conditions and/or firing positions (standing/kneeling/prone).

These variables were analyzed using a two-way repeated measures analysis of variance (ANOVA). The ANOVA compared the test configurations across firing positions, for a 2 (mask condition) x 3 (firing position) design for the One Target scenario and a 2 (mask condition) x 2 (firing position) design for the Five Target scenario.

A statistically significant difference between scores means that the scores are indeed different and are not simply a result of a chance occurrence. All of the tests were conducted at a level where probability $p < 0.05$, meaning that there was a greater than 95% chance that the difference was true between data points (Hayes, W.L., 1981).

Any significant differences between scores depend on both the mean (average) and the variance (spread of values across subjects; the square of the standard deviation), as well as other factors. Differences that appear large may not, in fact, significantly differ, especially when the variance is also large.

3. Live Fire Results

3.1. The Effect of Mask Condition on Aimed Shooting Performance (Pop-Up Target Scenario)

There were no significant effects of mask condition on target radial error, time of shot, or hit rate (see Figures 12-14 and Tables 4-6; error bars represent Standard Error).

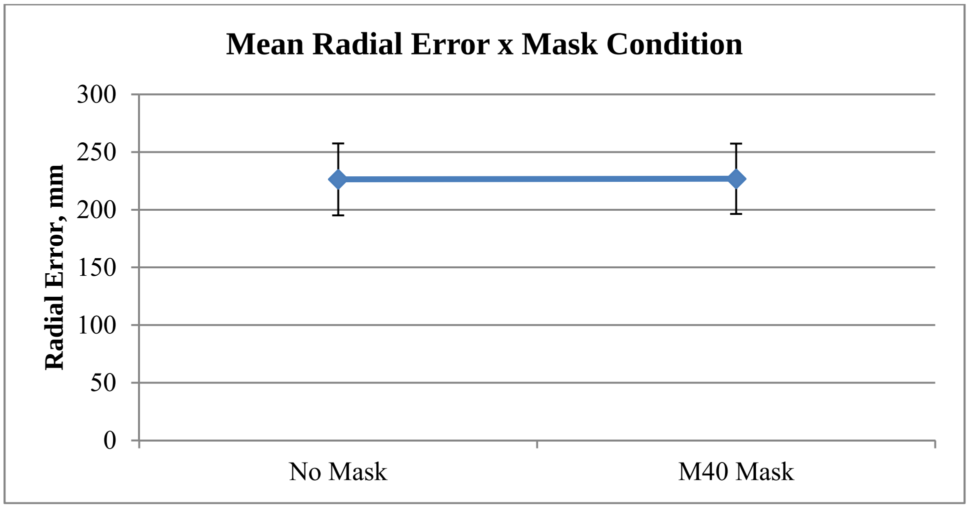

Figure 12. The mean radial error by mask condition for aimed fire of pop-up targets

Table 4. Live Fire: Radial Error by Mask Condition (mm)					
No Mask		Mask		*F*	*p*
Mean	S.D.	Mean	S.D.		
226.31	103.38	226.82	101.09	0.03	0.86
A		A			

Note: A>B, different letters indicate significant differences at the $p < 0.05$ level

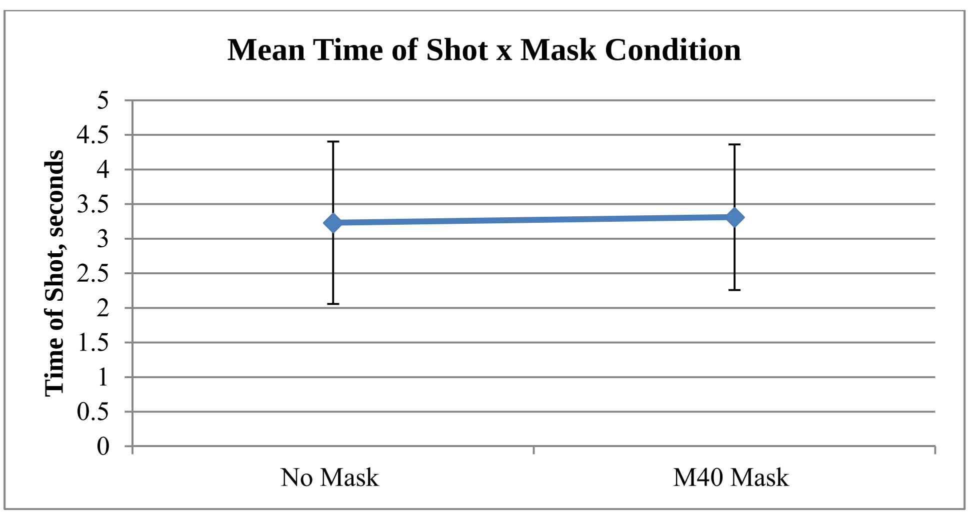

Figure 13. The mean time of shot by mask condition for aimed fire of pop-up targets

Table 5. Live Fire: Time of Shot by Mask Condition (s)					
No Mask		Mask		*F*	*p*
Mean	S.D.	Mean	S.D.		
3.23	3.89	3.31	3.49	0.52	0.49
A		A			

Note: A>B, different letters indicate significant differences at the p < 0.05 level

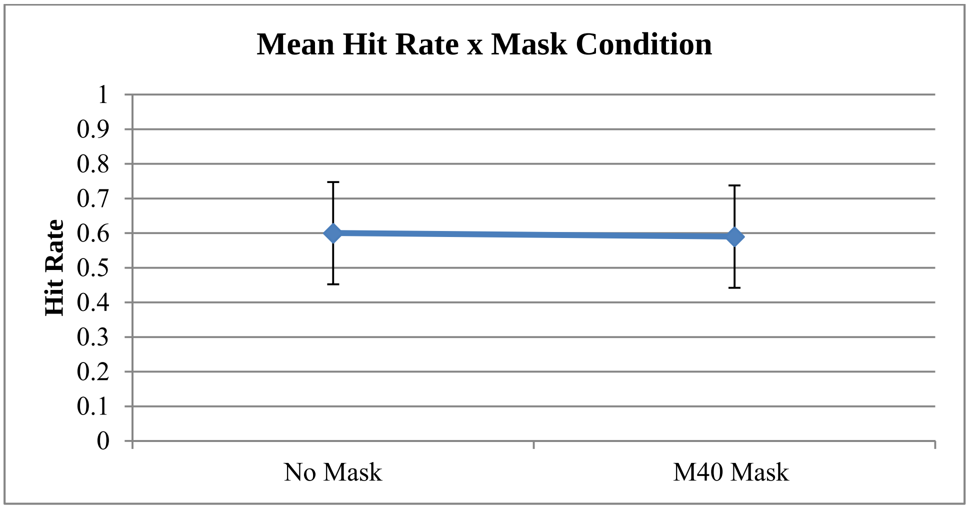

Figure 14. The mean hit rate by mask condition for aimed fire of pop-up targets

Table 6. Live Fire: Hit Rate by Mask Condition					
No Mask		Mask		*F*	*p*
Mean	S.D.	Mean	S.D.		
0.60	0.26	0.59	0.28	0.28	0.61
A		A			

Note: A>B, different letters indicate significant differences at the p < 0.05 level

3.2. The Effect of Body Position on Aimed Shooting Performance (Pop-Up Target Scenario)

A significant interaction radial error for body posture by range was found ($F(4.0, 45.63) = 5.26$, $p < 0.01$).

For hit rate data, a significant main effect of body posture ($F(2, 20.1) = 67.26$, $p < 0.01$) was found. However, Tukey's HSD post-hoc analyses showed that for hit rate, each body posture and range to target were not significantly different from each other. The ANOVA showed a significant main effect, but the Tukey's HSD showed no significant differences from any of the conditions.

There were no significant effects of body posture on time of shot or hit time (see Figures 15-17 and Tables 7-9; error bars represent Standard Error).

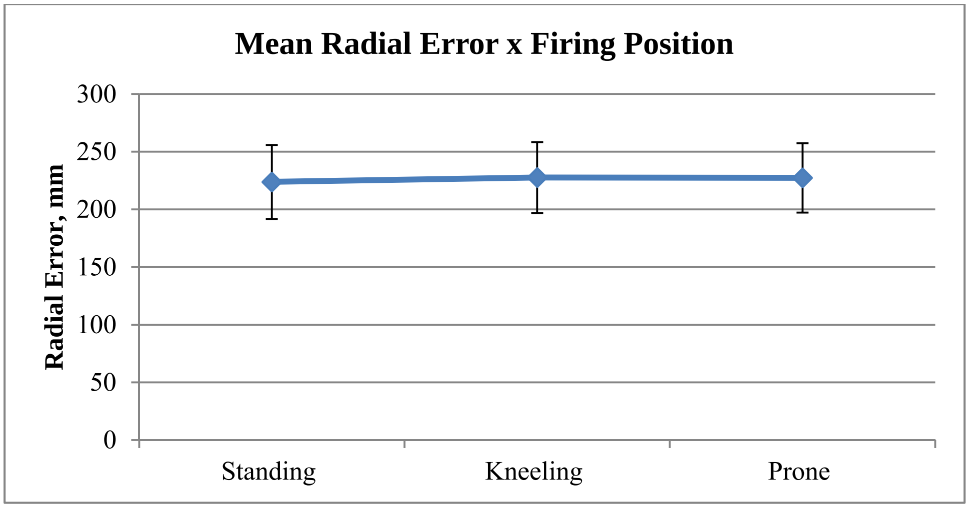

Figure 15. The mean radial error by firing position for aimed fire of pop-up targets

Table 7. Live Fire: Radial Error by Firing Position (mm)							
Standing Unsupported		**Kneeling Unsupported**		**Prone Unsupported**		***F***	***p***
Mean	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**		
223.77	106.43	227.58	102.11	227.33	99.82	0.51	0.61
A		A		A			

Note: A>B>C, different letters indicate significant differences at the $p < 0.05$ level

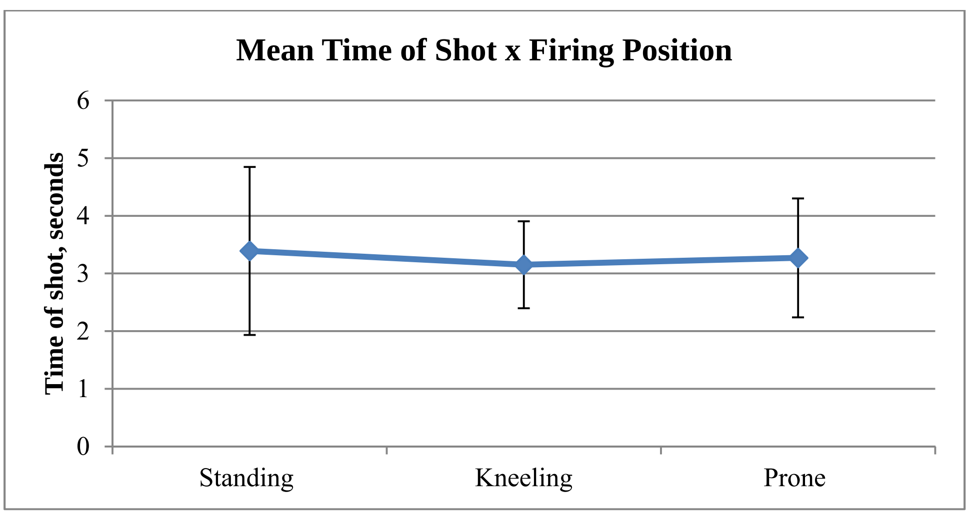

Figure 16. The mean time of shot by firing position for aimed fire of pop-up targets

Table 8. Live Fire: Time of Shot by Firing Position (s)							
Standing Unsupported		**Kneeling Unsupported**		**Prone Unsupported**		***F***	***p***
Mean	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**		
3.39	4.83	3.15	2.50	3.27	3.42	0.14	0.87
A		A		A			

Note: A>B>C, different letters indicate significant differences at the $p < 0.05$ level

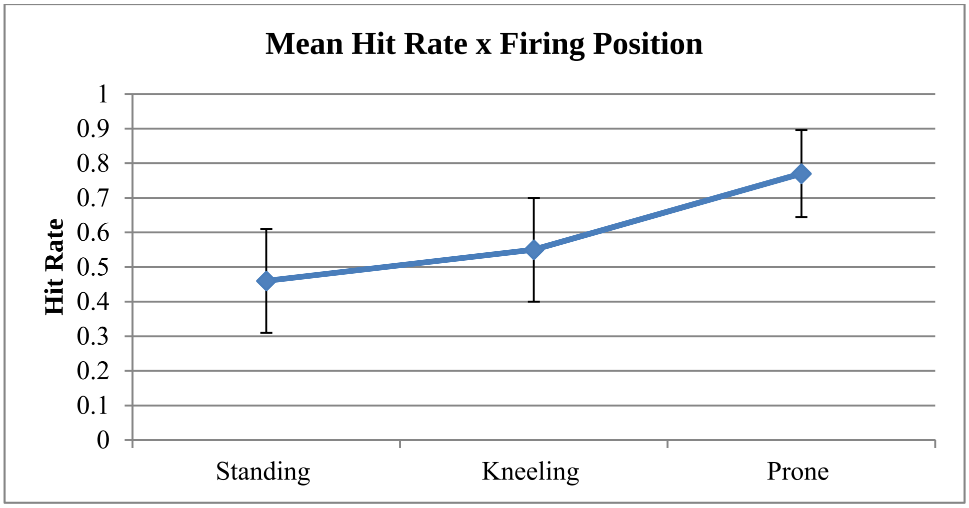

Figure 17. The significant effect of firing position on hit rate for aimed fire of pop-up targets.

Table 9. Live Fire: Hit Rate by Firing Position							
Standing Unsupported		**Kneeling Unsupported**		**Prone Unsupported**		***F***	***p***
Mean	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**		
0.46	0.50	0.55	0.50	0.77	0.42	58.68	<0.01
B		AB		A			

Note: A>B>C, different letters indicate significant differences at the $p < 0.05$ level

3.3. The Effect of Target Distance on Aimed Shooting Performance (Pop-Up Target Scenario)

For the target radial error data, a significant main effect of distance to target ($F(2, 21.2) = 6.77$, $p < 0.01$) was found. Tukey's HSD post-hoc analyses showed that for aimed fire, each target distance was significantly different from each other. Radial error increased significantly from one distance to the next as target distance increased.

Also, for hit rate data, a significant main effect of distance to target ($F(2, 20.1) = 80.33$, $p < 0.01$) was found. Tukey's HSD post-hoc analyses showed that for hit rate, each body posture and range to target were not significantly different from each other. The ANOVA showed a significant main effect, but the Tukey's HSD showed no significant differences from any of the conditions (see Figures 18-20 and Tables 10-12; error bars represent Standard Error).

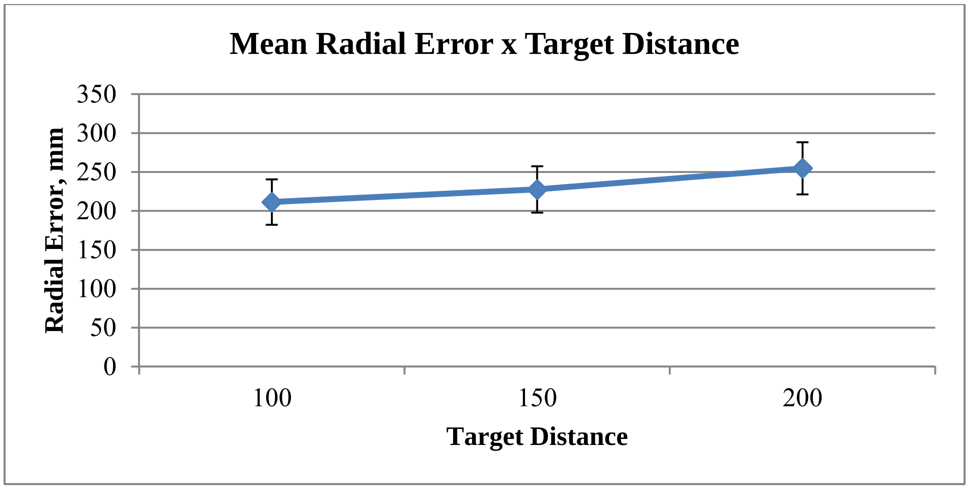

Figure 18. The significant effect of target distance on radial error for aimed fire of pop-up targets

Table 10. Live Fire: Radial Error by Target Distance (mm)							
100 m		**150 m**		**200 m**		***F***	***p***
Mean	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**		
211.33	96.52	227.58	98.55	254.76	111.25	6.77	<0.01
C		B		A			

Note: A>B>C, different letters indicate significant differences at the p < 0.05 level

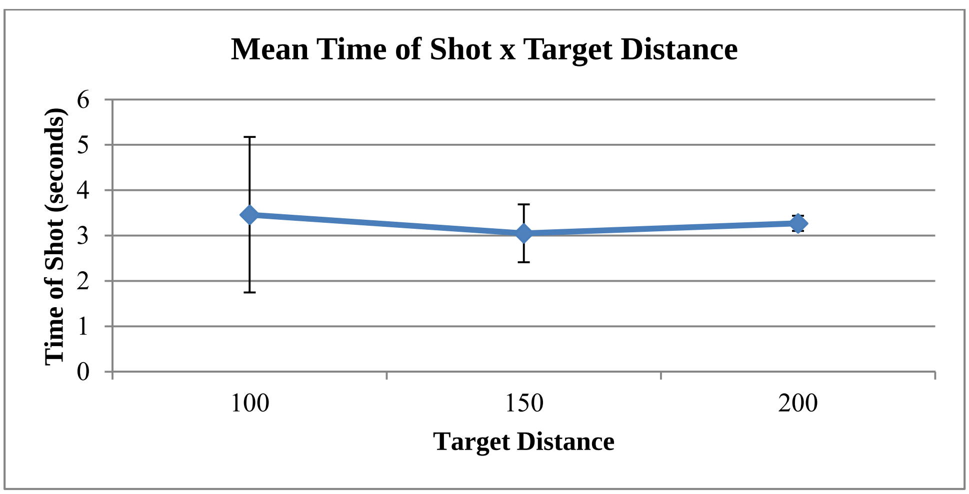

Figure 19. The mean time of shot by target distance for aimed fire of pop-up targets

Table 11. Live Fire: Time of Shot by Target Distance (s)							
100 m		**150 m**		**200 m**		***F***	***p***
Mean	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**		
3.46	5.68	3.05	2.12	3.27	0.56	1.17	0.33
A		A		A			

Note: A>B>C, different letters indicate significant differences at the p < 0.05 level

Figure 20. The significant effect of target distance on hit rate for aimed fire pop-up targets

Table 12. Live Fire: Hit Rate by Target Distance							
100 m		150 m		200 m		*F*	*p*
Mean	S.D.	Mean	S.D.	Mean	S.D.		
0.81	0.40	0.52	0.50	0.45	0.50	12.67	<0.01
A		B		B			

Note: A>B>C, different letters indicate significant differences at the p < 0.05 level

3.4. Live Fire Discussion

The effects of the M40 CB mask were not significant. The only significant effects were range to target on radial error and body posture by range. Also, for hit rate, a main effect was found for body posture and range to target.

Radial error increased as target range increased. Hit rate decreased with increase of target range and body postures – prone, kneeling, and standing, respectively.

An increase in range caused a decrease in shooting performance since farther targets are more difficult to successfully engage. Further, body posture, such as kneeling and standing when unsupported, cause a challenge for the shooter to engage the target. This is reflected in the live fire data where the shooter typically performs better in the prone position.

The TPs had prior training experience shooting while wearing CB masks. The TPs were given training time in all scenarios during this study prior to record trials. Therefore, the TPs were able to adapt, successfully engage the target, and perform as well as when they were not wearing the CB mask.

4. WEAPON SIMULATOR RESULTS

4.1. One-Target Results

4.1.1. Mask Comparison – B-Distance

A 2x3 repeated measures ANOVA was performed to reveal the effect of mask configuration on B-Distance (TV, shot accuracy) for the One-Target scenario. The mask configuration had no significant effect on B-distance, $F(1.0, 11.0) = 1.61$, $p = 0.23$.

As shown in Table 13 and Figure 21, TPs tended to hit closer to the center of the target in the No Mask configuration ($M = 112.05$ mm) than in the M40 Mask configuration ($M = 130.19$ mm); however, the difference between Mask and No Mask conditions did not reach statistical significance, $p > 0.05$ (error bars represent Standard Error).

Table 13. One Target B-Distance Results for Mask Configuration (mm)

No Mask		Mask		*F*	*p*
Mean	**S.D.**	**Mean**	**S.D.**		
112.05	28.65	130.19	35.61	1.61	0.23
A		A			

Note: A>B, different letters indicate significant differences at the p < 0.05 level

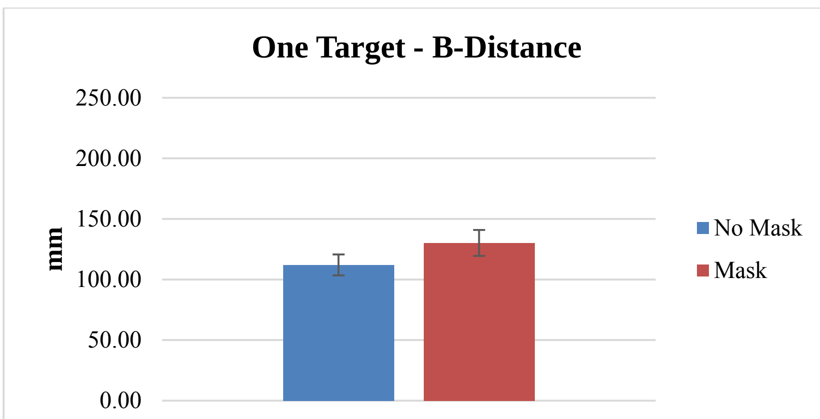

Figure 21. Mean and Standard Error of One-Target B-Distance (Accuracy) for Mask Configuration

4.1.2. Mask Comparison – E-Distance

A 2x3 repeated measures ANOVA was performed to reveal the effect of mask configuration on E-Distance (VE, shot cluster) for the One-Target scenario. The mask configuration had no significant effect on E-distance, $F(1.0, 10.0) = 0.44$, $p = 0.52$.

As shown in Table 14 and Figure 22, TPs performed about the same in terms of shot group tightness regardless of mask configuration, $p > 0.05$ (error bars represent Standard Error).

Table 14. One Target E-Distance Results for Mask Configuration (mm)					
No Mask		Mask		*F*	*p*
Mean	S.D.	Mean	S.D.		
66.58	18.95	70.54	15.94	0.44	0.52
A		A			

Note: A>B, different letters indicate significant differences at the p < 0.05 level

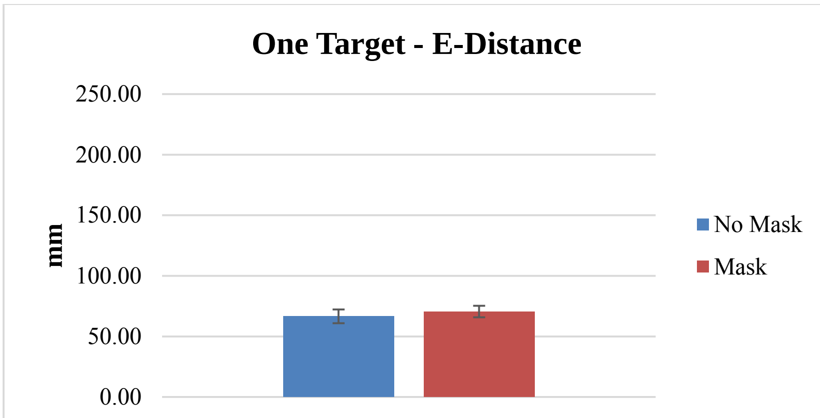

Figure 22. Mean and Standard Error of One-Target E-Distance (Shot Group Tightness) Results for Mask Configuration

4.1.3. Firing Position Comparison – B-Distance

While not the main focus of this evaluation, the effect of firing position on B-Distance (TV, shot accuracy) was also examined for the One-Target scenario. The results showed that firing position did not have a significant effect on B-distance, $F(2.0, 20.0) = 2.99$, $p = 0.07$.

As shown in Table 15 and Figure 23, mean B-Distance values in the Prone Unsupported firing position ($M = 105.95$ mm) were the smallest (indicating better performance: shots closer to the center of the target), followed by the Kneeling Unsupported firing position ($M = 123.11$ mm) and then the Standing Unsupported firing position ($M = 134.31$ mm); however, the differences were not statistically significant, $p > 0.05$.

Table 15. One Target B-Distance Results for Firing Position (mm)							
Standing Unsupported		Kneeling Unsupported		Prone Unsupported		*F*	*p*
Mean	S.D.	Mean	S.D.	Mean	S.D.		
134.31	32.18	123.11	27.90	105.95	33.66	2.99	0.07
A		A		A			

Note: A>B>C, different letters indicate significant differences at the p < 0.05 level

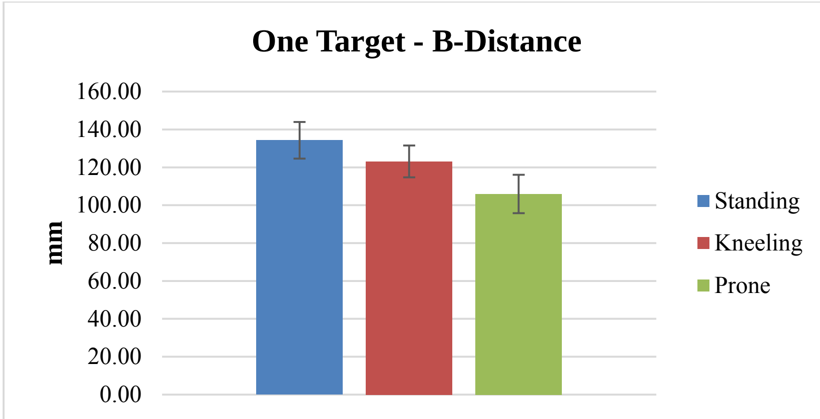

Figure 23. Mean and Standard Error of One-Target B-Distance (Accuracy) Results for Firing Position

4.1.4. Firing Position Comparison – E-Distance

Again, while not the main focus of this evaluation, the effect of firing position on E-Distance (VE, shot cluster) was also examined for the One-Target scenario. The results show that firing position had a significant effect on E-distance, $F(2.0, 20.0) = 36.72$, $p = 0.01$.

As shown in Table 16 and Figure 24, E-Distance in the Prone Unsupported firing position (M = 47.01 mm) was significantly smaller (indicating better performance: tighter shot groupings) than in the Kneeling Unsupported (M = 68.75 mm) or Standing Unsupported firing position (M = 89.91 mm), $p < 0.05$. E-Distance values in the Kneeling Unsupported firing position were also significantly smaller than in the Standing Unsupported firing position, $p < 0.05$ (error bars represent Standard Error).

Table 16. One Target E-Distance Results for Firing Position (mm)

Standing Unsupported		Kneeling Unsupported		Prone Unsupported		*F*	*p*
Mean	S.D.	Mean	S.D.	Mean	S.D.		
89.91	20.94	68.75	16.55	47.01	13.64	36.72	0.01
A		B		C			

Note: A>B>C, different letters indicate significant differences at the p < 0.05 level

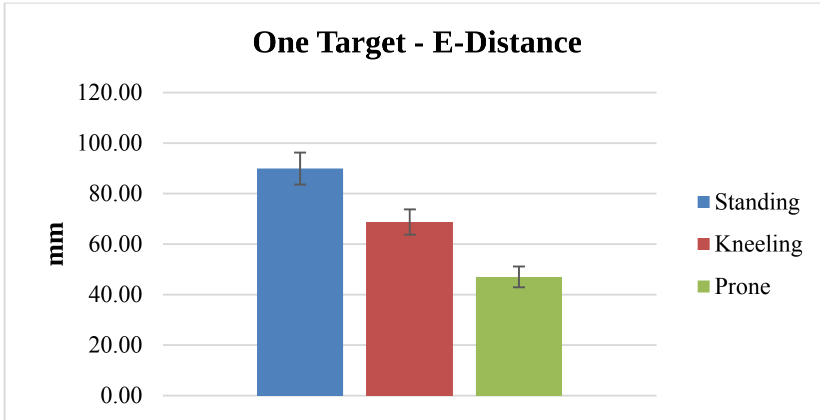

Figure 24. Mean and Standard Error of One-Target E-Distance (Shot Group Tightness) Results for Firing Position

4.1.5. Interaction Effects – B-Distance

There were no significant interaction effects between mask configuration and firing position for B-Distance in the One-Target scenario.

4.1.6. Interaction Effects – E-Distance

There were no significant interaction effects between mask configuration and firing position for E-Distance in the One-Target scenario.

4.1.7. Statistical Summary – One Target Results

Table 17 presents a summary of the statistical results. Additional tables and graphs showing results for the One Target scenario (both Mask Configuration and Firing Position results) can be found in Appendix B.

Table 17. 1-Target ANOVA Results

Main Effect	B-Distance	E-Distance
Mask Configuration	NS	NS
Position Comparison	NS	<0.01
Interaction Effects	NS	NS

Note: Green cells indicate comparisons that were significantly different
NS = Not Significant

4.2. Five-Target Results

4.2.1. Mask Comparison – B-Distance

A 2x2 repeated measures ANOVA was performed to reveal the effect of mask configuration on B-Distance (TV, shot accuracy) for the Five-Target scenario.

As shown in Table 18 and Figure 25, TPs tended to hit closer to the center of the target in the No Mask configuration ($M_{All\ Targets}$[3] = 177.56 mm) than in the M40 Mask configuration (M = 204.98

[3] $M_{All\ Targets}$ is the mean of all target locations for a given configuration

mm); however, the difference between Mask and No Mask conditions did not reach statistical significance for any of the target locations, $p > 0.05$ (error bars represent Standard Error).

Table 18. Five Target B-Distance Results for Mask Configuration (mm)

Target Location	No Mask		Mask		*F*	DF	*p*
	Mean	S.D.	Mean	S.D.			
Center	156.67	42.99	184.51	60.79	1.56	1.0, 10.0	0.24
	A		A				
Left High	193.12	42.50	225.94	58.10	2.14	1.0, 10.0	0.17
	A		A				
Left Low	177.25	44.58	199.45	45.74	1.47	1.0, 10.0	0.25
	A		A				
Right High	185.76	52.54	224.39	56.48	2.44	1.0, 10.0	0.15
	A		A				
Right Low	174.97	45.81	190.61	66.08	0.51	1.0, 10.0	0.49
	A		A				

Note: A>B, different letters indicate significant differences at the $p < 0.05$ level

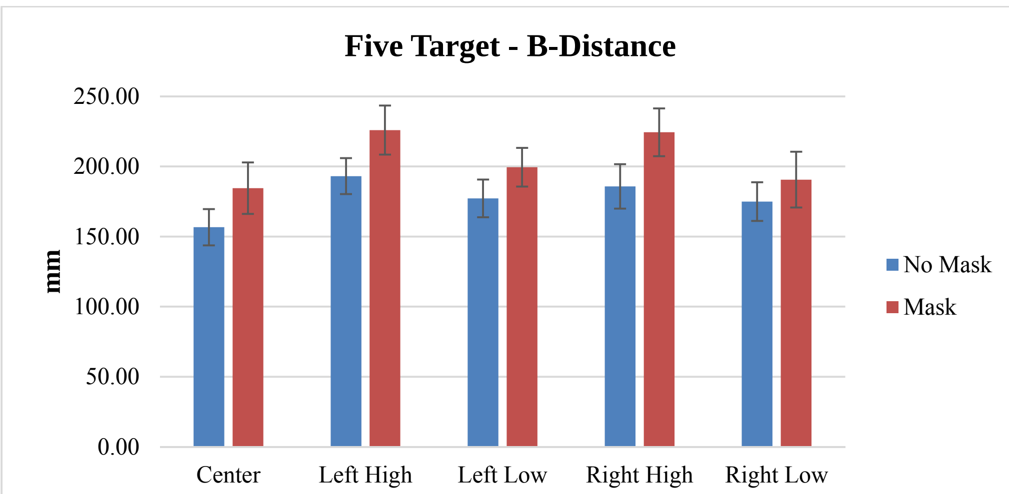

Figure 25. Mean and Standard Error of Five-Target B-Distance (Accuracy) Results for Mask Configuration

4.2.2. Mask Comparison – E-Distance

A 2x2 repeated measures ANOVA was performed to reveal the effect of mask configuration on E-Distance (VE, shot cluster) for the Five-Target scenario.

As shown in Table 19 and Figure 26, E-Distance did not significantly differ between mask configurations for the Five Target scenario, $p > 0.05$ (error bars represent Standard Error).

Table 19. Five Target E-Distance Results for Mask Configuration (mm)							
Target Location	No Mask		Mask		*F*	DF	*p*
	Mean	S.D.	Mean	S.D.			
Center	123.72	31.01	138.52	49.93	0.94	1.0, 10.0	0.36
	A		A				
Left High	156.31	40.05	156.16	33.21	0.01	1.0, 10.0	0.99
	A		A				
Left Low	148.61	42.13	158.39	39.74	0.36	1.0, 10.0	0.56
	A		A				
Right High	146.99	39.48	168.05	35.70	2.76	1.0, 10.0	0.13
	A		A				
Right Low	142.79	42.00	155.42	43.63	0.73	1.0, 10.0	0.41
	A		A				

Note: A>B, different letters indicate significant differences at the $p < 0.05$ level

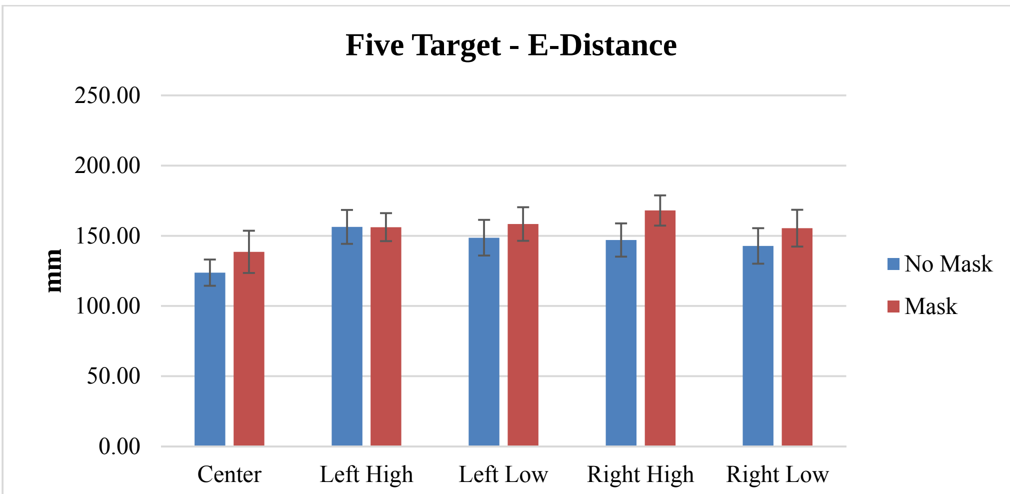

Figure 26. Mean and Standard Error of Five-Target E-Distance (Shot Group Tightness) Results for Mask Configuration

4.2.3. Mask Comparison – Total Time

A 2x2 repeated measures ANOVA was performed to reveal the effect of mask configuration on Total Time between shots for the Five-Target scenario.

As shown in Table 20 and Figure 27, TPs were significantly faster in the No Mask configuration ($M_{\text{All Targets}}$ = 2.82 s) than in the M40 Mask configuration ($M_{\text{All Targets}}$ = 3.43 s) for all movement arcs except for Center → Left Low and Right High → Left Low, $p < 0.05$. The TPs were also faster in the No Mask configuration in these two movement arcs, but the differences were not statistically significant, $p > 0.05$ (error bars represent Standard Error).

Table 20. Five Target Total Time Results for Mask Configuration (s)							
Target Location	**No Mask**		**Mask**		***F***	**DF**	***p***
	Mean	**S.D.**	**Mean**	**S.D.**			
Center → Left Low	2.75	0.99	3.20	1.68	3.29	1.0, 10.0	0.10
	A		A				
Center → Right Low	2.79	0.96	3.42	1.69	5.11	1.0, 10.0	0.05
	B		A				
Left Low → Left High	2.40	0.85	2.98	1.38	9.59	1.0, 10.0	0.01
	B		A				
Left High → Right Low	3.21	1.21	3.87	1.92	5.34	1.0, 10.0	0.04
	B		A				
Right High → Left Low	3.25	0.96	4.09	2.14	3.95	1.0, 10.0	0.08
	A		A				
Right Low → Right High	2.52	1.00	3.03	1.55	6.57	1.0, 10.0	0.03
	B		A				

Note: A>B, different letters indicate significant differences at the p < 0.05 level

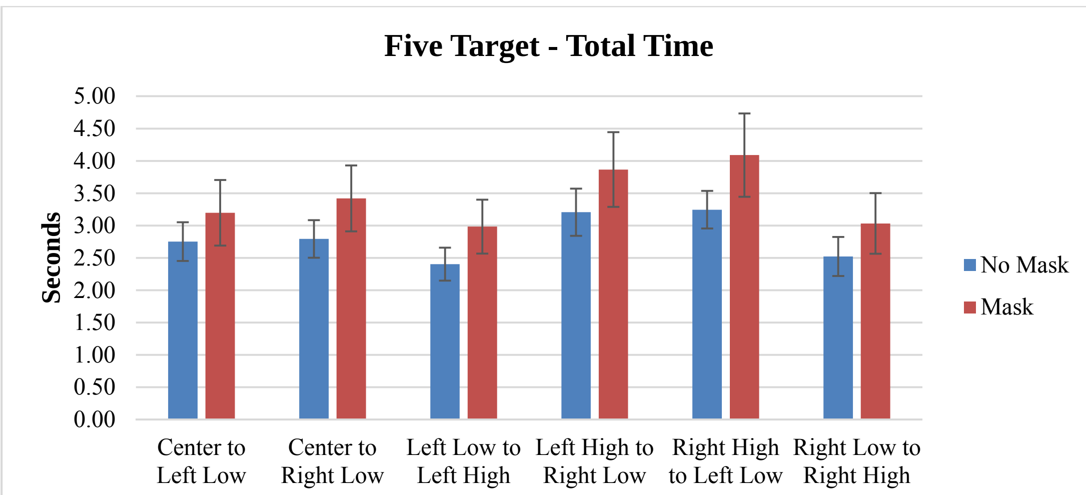

Figure 27. Mean and Standard Error of Five Target Total Time Results for Mask Configuration

4.2.4. Mask Comparison – Aiming Time

A 2x2 repeated measures ANOVA was performed to reveal the effect of mask configuration on Aiming Time for the Five-Target scenario.

As shown in Table 21 and Figure 28, TPs spent more time aiming at the target prior to firing in the M40 Mask configuration ($M_{All\ Targets}$ = 1.47 s) than in the No Mask configuration ($M_{All\ Targets}$ = 1.20 s), significantly so for the Center → Right Low, Left Low → Left High, and Right High → Left Low movement arcs, p < 0.05 (error bars represent Standard Error).

Table 21. Five Target Aiming Time Results for Mask Configuration (s)

Target Location	No Mask		Mask		*F*	DF	*p*
	Mean	S.D.	Mean	S.D.			
Center → Left Low	1.19	0.52	1.28	0.95	0.21	1.0, 10.0	0.66
	A		A				
Center → Right Low	1.19	0.62	1.47	0.95	4.50	1.0, 10.0	0.05
	B		A				
Left Low → Left High	1.14	0.53	1.47	0.91	5.26	1.0, 10.0	0.05
	B		A				
Left High → Right Low	1.16	0.55	1.47	0.96	3.23	1.0, 10.0	0.10
	A		A				
Right High → Left Low	1.25	0.58	1.63	1.07	4.89	1.0, 10.0	0.05
	B		A				
Right Low → Right High	1.25	0.64	1.51	0.99	3.46	1.0, 10.0	0.09
	A		A				

Note: A>B, different letters indicate significant differences at the $p < 0.05$ level

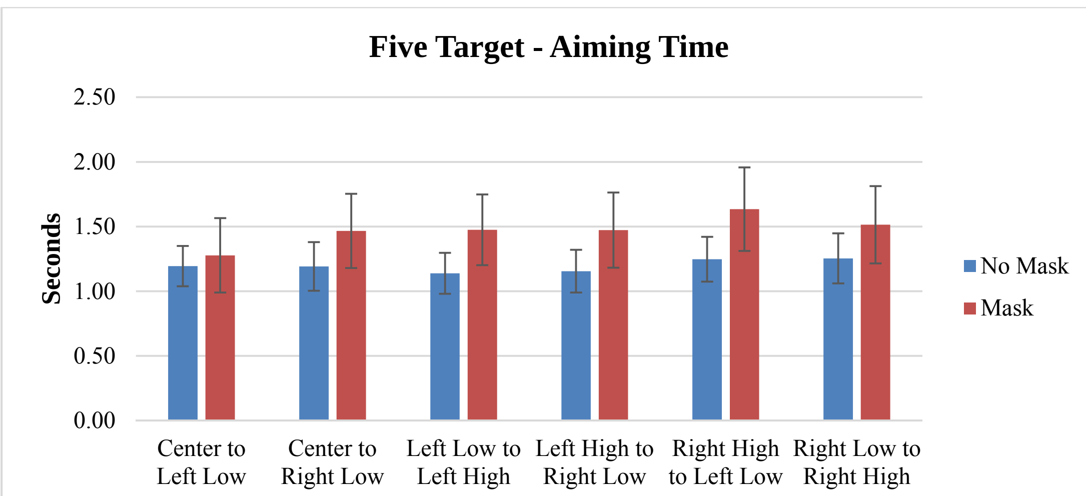

Figure 28. Mean and Standard Error of Five Target Aiming Time Results for Mask Configuration

4.2.5. Mask Comparison – Movement Time

A 2x2 repeated measures ANOVA was performed to reveal the effect of mask configuration on Movement Time for the Five-Target scenario.

As shown in Table 22 and Figure 29, TPs took longer to physically transition from one target to the next in the M40 Mask configuration ($M_{All\ Targets}$ = 1.96 s) than in the No Mask configuration ($M_{All\ Targets}$ = 1.62 s), significantly so for the Center → Left Low, Left Low → Left High, and Right Low → Right High movement arcs, $p < 0.05$ (error bars represent Standard Error).

Table 22. Five Target Movement Time Results for Mask Configuration (s)							
Target Location	**No Mask**		**Mask**		***F***	**DF**	***p***
	Mean	**S.D.**	**Mean**	**S.D.**			
Center → Left Low	1.56	0.50	1.92	0.88	7.32	1.0, 10.0	0.02
	B		A				
Center → Right Low	1.60	0.41	1.95	0.85	3.10	1.0, 10.0	0.11
	A		A				
Left Low → Left High	1.26	0.36	1.51	0.53	8.17	1.0, 10.0	0.02
	B		A				
Left High → Right Low	2.05	0.71	2.39	1.26	2.87	1.0, 10.0	0.12
	A		A				
Right High → Left Low	2.00	0.45	2.45	1.33	2.23	1.0, 10.0	0.17
	A		A				
Right Low → Right High	1.27	0.42	1.52	0.59	6.13	1.0, 10.0	0.03
	B		A				

Note: A>B, different letters indicate significant differences at the p < 0.05 level

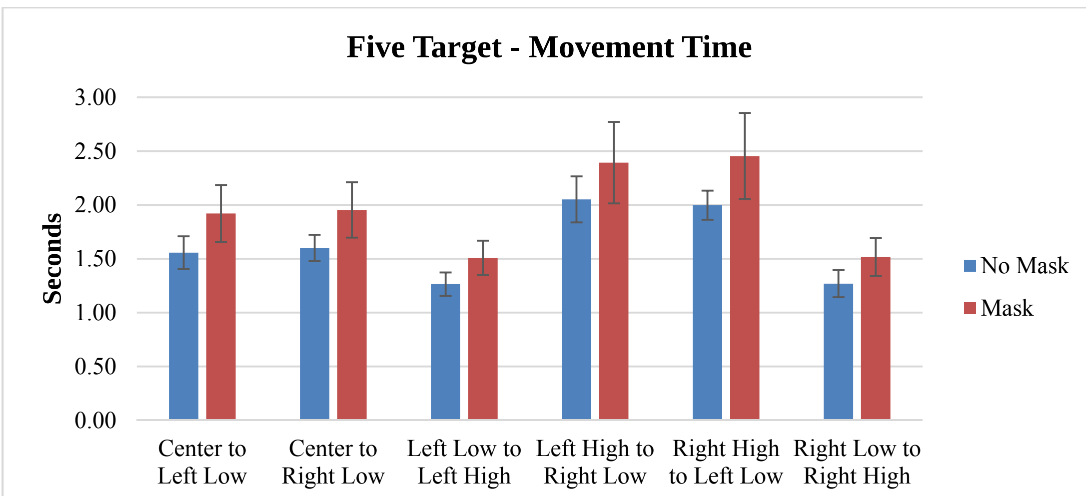

Figure 29. Mean and Standard Error of Five Target Movement Time Results for Mask Configuration

4.2.6. Firing Position Comparison – B-Distance

Again, while not the main focus of this evaluation, a 2x2 repeated measures ANOVA was performed to reveal the effect of firing position on B-Distance (TV, shot accuracy) for the Five-Target scenario.

As shown in Table 23 and Figure 30, B-Distance values for the Kneeling Unsupported firing position were significantly lower (indicating better performance: shots were closer to the center of the target) than in the Standing Unsupported firing position for both the Center target location ($M_{Kneeling} = 154.43$, $M_{Standing} = 186.75$) and the Right Low target location ($M_{Kneeling} = 169.59$, $M_{Standing} = 196.00$), $p < 0.05$. B-Distance values were also lower in the Kneeling Unsupported firing position than in the Standing Unsupported firing position for the other target locations, with the exception of the Right High target location, however they did not significantly differ, $p > 0.05$ (error bars represent Standard Error).

Table 23. Five Target B-Distance Results for Firing Position (mm)							
Target Location	**Standing Unsupported**		**Kneeling Unsupported**		***F***	**DF**	***p***
	Mean	**S.D.**	**Mean**	**S.D.**			
Center	186.75	36.90	154.43	46.86	7.72	1.0, 10.0	0.02
	A		B				
Left High	214.44	34.83	204.63	37.71	2.42	1.0, 10.0	0.15
	A		A				
Left Low	197.40	37.59	179.29	38.79	2.62	1.0, 10.0	0.14
	A		A				
Right High	201.61	36.64	208.54	43.46	0.41	1.0, 10.0	0.54
	A		A				
Right Low	196.00	40.07	169.59	54.08	5.34	1.0, 10.0	0.04
	A		B				

Note: A>B, different letters indicate significant differences at the $p < 0.05$ level

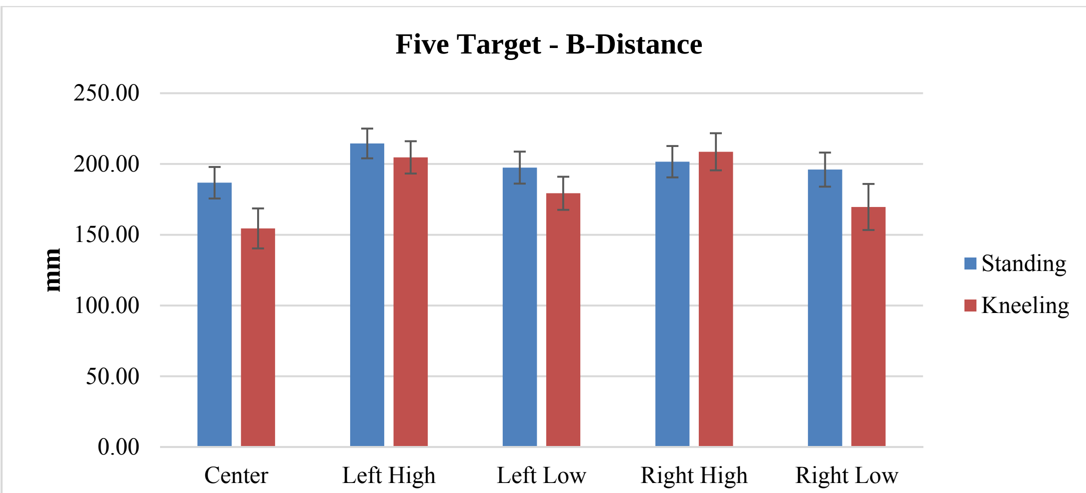

Figure 30. Mean and Standard Error of Five-Target B-Distance (Accuracy) Results for Firing Position

4.2.7. Firing Position Comparison – E-Distance

A 2x2 repeated measures ANOVA was performed to reveal the effect of firing position on E-Distance (VE, shot cluster) for the Five-Target scenario.

As shown in Table 24 and Figure 31, E-Distance values were consistently higher (indicating worse performance: shot groupings were larger) in the Standing Unsupported firing position than in the Kneeling Unsupported firing position, significantly so for the Left High target. For the Left High target, E-Distance values for the Standing Unsupported firing position (M = 164.62 mm) were significantly higher than in the Kneeling Unsupported firing position (M = 147.85 mm), $p < 0.05$ (error bars represent Standard Error).

Table 24. Five Target E-Distance Results for Firing Position (mm)							
Target Location	**Standing Unsupported**		**Kneeling Unsupported**		***F***	**DF**	***p***
	Mean	**S.D.**	**Mean**	**S.D.**			
Center	151.49	50.07	110.75	42.46	4.26	1.0, 10.0	0.07
	A		A				
Left High	164.62	34.14	147.85	30.62	7.68	1.0, 10.0	0.02
	A		B				
Left Low	156.46	33.43	150.54	33.83	0.55	1.0, 10.0	0.48
	A		A				
Right High	153.00	27.70	162.05	37.43	2.06	1.0, 10.0	0.18
	A		A				
Right Low	158.31	42.29	139.90	36.98	2.71	1.0, 10.0	0.13
	A		A				

Note: A>B, different letters indicate significant differences at the p < .05 level

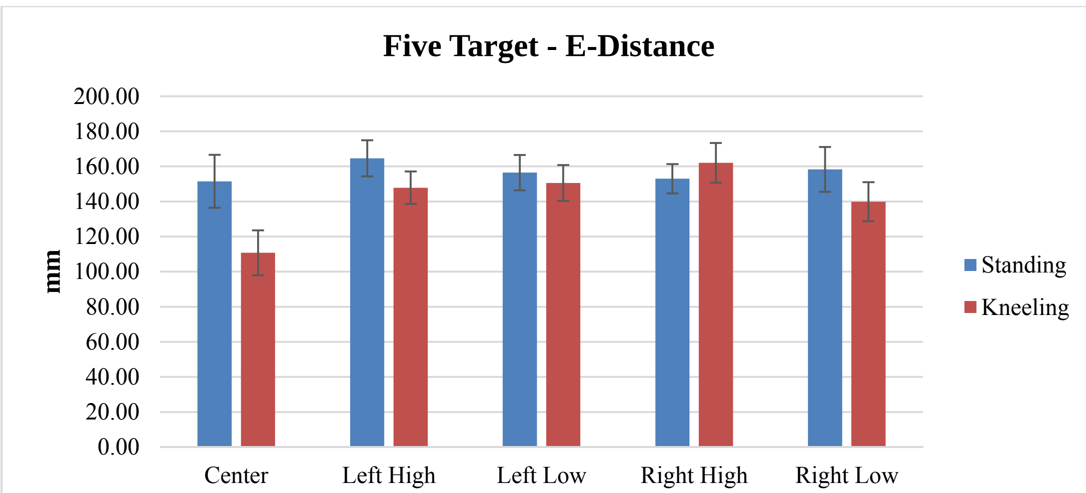

Figure 31. Mean and Standard Error of Five-Target E-Distance (Shot Group Tightness) Results for Firing Position

4.2.8. Firing Position Comparison – Total Time

A 2x2 repeated measures ANOVA was performed to reveal the effect of firing position on Total Time between shots for the Five-Target scenario.

As shown in Table 25 and Figure 32, Total Time values were significantly faster in the Standing Unsupported firing position ($M_{All\ Targets}$ = 2.78 s) than in the Kneeling Unsupported firing position ($M_{All\ Targets}$ = 3.47 s) for all movement arcs with the exception of the Center → Right Low movement arc, $p < 0.05$. For the Center → Right Low movement arc the TPs were also faster in the Standing Unsupported firing position (M = 2.82 s) than in the Kneeling Unsupported firing position (M = 3.40 s); however, the difference between the two firing positions did not reach statistical significance, $p > 0.05$ (error bars represent Standard Error).

Table 25. Five Target Total Time Results for Firing Position (s)							
Target Location	**Standing Unsupported**		**Kneeling Unsupported**		***F***	**DF**	***p***
	Mean	**S.D.**	**Mean**	**S.D.**			
Center → Left Low	2.68	0.99	3.27	1.69	5.30	1.0, 10.0	0.04
	B		A				
Center → Right Low	2.82	0.90	3.40	1.74	4.11	1.0, 10.0	0.07
	A		A				
Left Low → Left High	2.49	0.96	2.89	1.25	19.33	1.0, 10.0	0.01
	B		A				
Left High → Right Low	3.05	0.99	4.02	2.10	7.16	1.0, 10.0	0.02
	B		A				
Right High → Left Low	3.28	1.29	4.06	1.75	14.35	1.0, 10.0	0.01
	B		A				
Right Low → Right High	2.37	0.95	3.19	1.62	11.39	1.0, 10.0	0.01
	B		A				

Note: A>B, different letters indicate significant differences at the p < .05 level

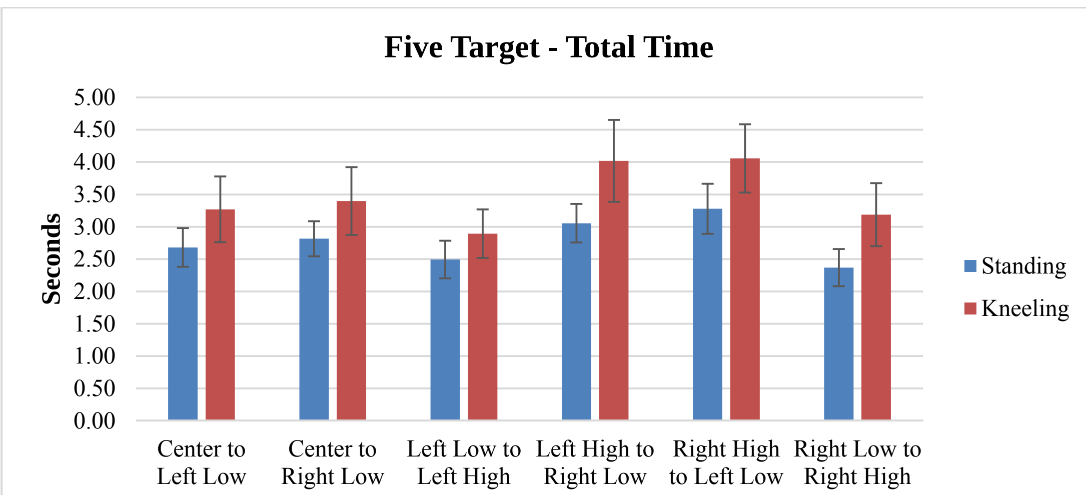

Figure 32. Mean and Standard Error of Five Target Total Time Results for Firing Position

4.2.9. Firing Position Comparison – Aiming Time

A 2x2 repeated measures ANOVA was performed to reveal the effect of firing position on Aiming Time for the Five-Target scenario.

As shown in Table 26 and Figure 33, Aim Time values tended to be faster in the Standing Unsupported firing position ($M_{\textit{All Targets}}$ = 1.22 s) than in the Kneeling Unsupported firing position ($M_{\textit{All Targets}}$ = 1.45 s), significantly so for the Left Low → Left High, Left High → Right Low, and Right Low → Right High movement arcs, $p < 0.05$ (error bars represent Standard Error).

Table 26. Five Target Aiming Time Results for Firing Position (s)							
Target Location	**Standing Unsupported**		**Kneeling Unsupported**		***F***	**DF**	***p***
	Mean	**S.D.**	**Mean**	**S.D.**			
Center → Left Low	1.16	0.65	1.31	0.78	4.48	1.0, 10.0	0.06
	A		A				
Center → Right Low	1.19	0.58	1.47	0.98	4.73	1.0, 10.0	0.06
	A		A				
Left Low → Left High	1.21	0.70	1.40	0.72	7.01	1.0, 10.0	0.02
	B		A				
Left High → Right Low	1.22	0.70	1.41	0.77	5.33	1.0, 10.0	0.04
	B		A				
Right High → Left Low	1.38	0.73	1.50	0.91	1.49	1.0, 10.0	0.25
	A		A				
Right Low → Right High	1.19	0.64	1.58	0.97	11.22	1.0, 10.0	0.01
	B		A				

Note: A>B, different letters indicate significant differences at the p < .05 level

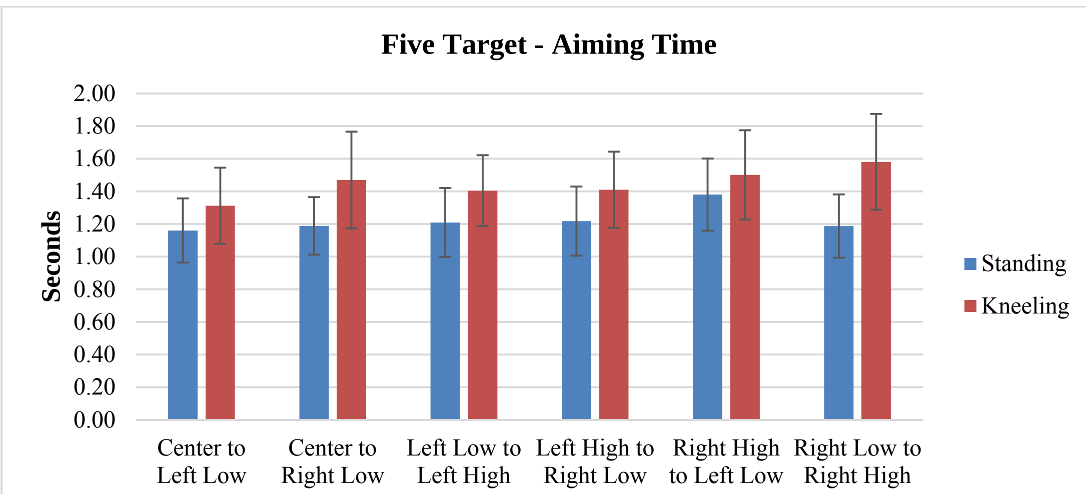

Figure 33. Mean and Standard Error of Five Target Aiming Time Results for Firing Position

4.2.10. Firing Position Comparison – Movement Time

A 2x2 repeated measures ANOVA was performed to reveal the effect of firing position on Movement Time for the Five-Target scenario.

As shown in Table 27 and Figure 34, Movement Time values tended to be faster in the Standing Unsupported firing position ($M_{\textit{All Targets}}$ = 1.56 s) than in the Kneeling Unsupported firing position ($M_{\textit{All Targets}}$ = 2.02 s) for all movement arcs, significantly so for the Left High → Right Low, Right High → Left Low, and Right Low → Right High movement arcs, $p < 0.05$ (error bars represent Standard Error).

Table 27. Five Target Movement Time Results for Firing Position (s)							
Target Location	**Standing Unsupported**		**Kneeling Unsupported**		***F***	**DF**	***p***
	Mean	**S.D.**	**Mean**	**S.D.**			
Center → Left Low	1.52	0.41	1.96	1.01	3.88	1.0, 10.0	0.08
	A		A				
Center → Right Low	1.63	0.41	1.93	0.83	2.82	1.0, 10.0	0.12
	A		A				
Left Low → Left High	1.28	0.30	1.49	0.58	4.00	1.0, 10.0	0.07
	A		A				
Left High → Right Low	1.84	0.44	2.61	1.52	4.98	1.0, 10.0	0.05
	B		A				
Right High → Left Low	1.90	0.71	2.56	1.01	29.85	1.0, 10.0	0.01
	B		A				
Right Low → Right High	1.18	0.36	1.61	0.66	10.36	1.0, 10.0	0.01
	B		A				

Note: A>B, different letters indicate significant differences at the p < .05 level

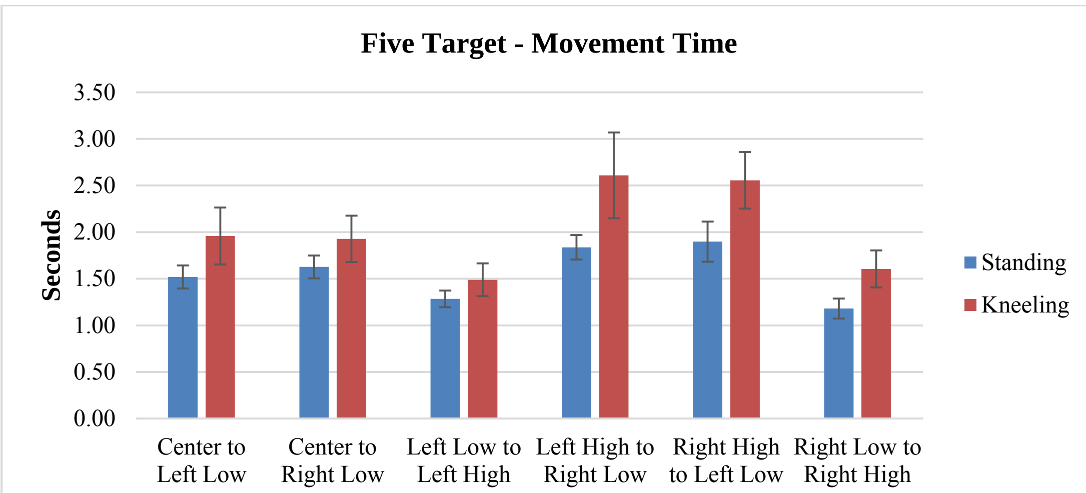

Figure 34. Mean and Standard Error of Five Target Movement Time Results for Firing Position

4.2.11. Interaction Effects – B-Distance

There were no significant interaction effects between mask configuration and firing position for B-Distance in the Five-Target scenario.

4.2.12. Interaction Effects – E-Distance

There were no significant interaction effects between mask configuration and firing position for E-Distance in the Five-Target scenario.

4.2.13. Interaction Effects – Total Time

There were no significant interaction effects between mask configuration and firing position for the majority of movement arcs in terms of Total Time in the Five Target scenario; however, there was a significant interaction effect between mask configuration and firing position for the Right High → Left Low movement arc, $F(1.0, 10.0) = 18.97$, $p = 0.01$.

In the M40 Mask configuration, Total Time did not significantly differ between Standing and Kneeling Unsupported firing positions; however, Total Time in the No Mask configuration was significantly higher (indicating worse performance: TPs took longer to fire the next shot) for the Kneeling Unsupported firing position ($M = 3.82$ s) than for the Standing Unsupported firing position ($M = 2.67$ s), $p < 0.05$.

It is possible the addition of the M40 mask slowed the TPs enough that firing position did not have a significant effect; however, this trend was not observed for any of the other movement arc directions.

Figure 35 depicts the different trends between mask configuration in each firing position (error bars represent Standard Error).

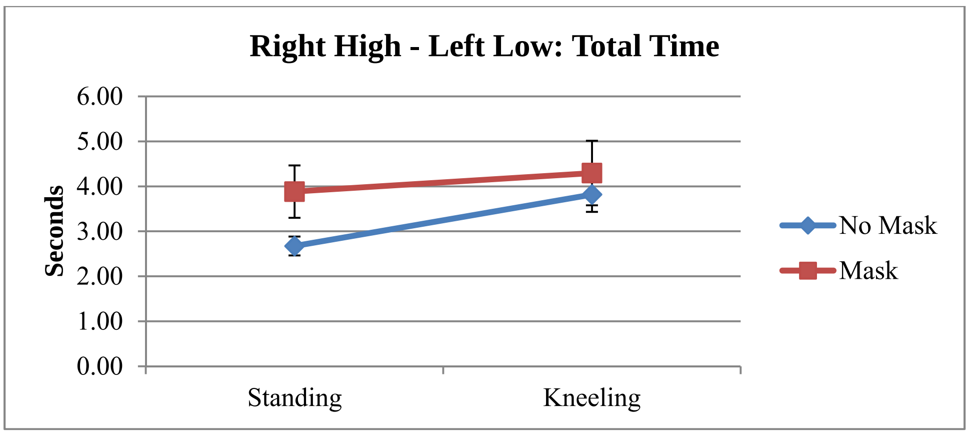

Figure 35. Mean and Standard Error of Interaction Effects: Right High → Left Low – Total Time

4.2.14. Interaction Effects – Aiming Time

There were no significant interaction effects between mask configuration and firing position for the majority of movement arcs in terms of Aiming Time in the Five Target scenario; however, there was a significant interaction effect between mask configuration and firing position for the Right High → Left Low movement arc, $F(1.0, 10.0) = 9.97$, $p = 0.01$.

In the M40 Mask configuration, Aiming Time did not significantly differ between Standing and Kneeling Unsupported firing positions; however, Total Time in the No Mask configuration was significantly higher (indicating worse performance: TPs took longer to fire the next shot) for the Kneeling Unsupported firing position ($M = 1.43$ s) than for the Standing Unsupported firing position ($M = 1.07$ s), $p < 0.05$.

It is possible that the addition of the M40 mask slowed the TPs enough that firing position did not have a significant effect; however, this trend was not observed for any of the other movement arc directions. It does align with the interaction effect for Total Time for the Right High → Left Low movement arc.

Figure 36 depicts the different trends between mask configuration in each firing position (error bars represent Standard Error).

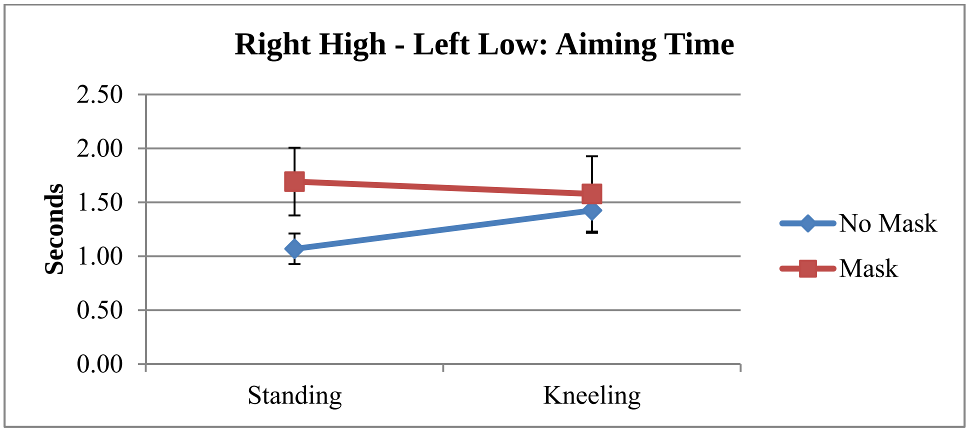

Figure 36. Mean and Standard Error of Interaction Effects: Right High → Left Low – Aiming Time

4.2.15. Interaction Effects – Movement Time

There were no significant interaction effects between mask configuration and firing position for Movement Time in the Five-Target scenario.

4.2.16. Statistical Summary – B-Distance and E-Distance

Table 28 presents a summary of the statistical results for B-Distance and E-Distance in the Five Target scenario.

Table 28. Five Target ANOVA Results: B-Distance and E-Distance		
Mask Comparison		
	B-Distance	**E-Distance**
Center	NS	NS
Left Low	NS	NS
Left High	NS	NS
Right Low	NS	NS
Right High	NS	NS
Position Comparison		
	B-Distance	**E-Distance**
Center	<0.05	NS
Left Low	NS	<0.05
Left High	NS	NS
Right Low	<0.05	NS
Right High	NS	NS
Interaction Effects		
	B-Distance	**E-Distance**
Center	NS	NS
Left Low	NS	NS
Left High	NS	NS
Right Low	NS	NS
Right High	NS	NS

Note: Green cells indicate comparisons that were significantly different
NS = Not Significant

4.2.17. Statistical Summary – Total Time, Aiming Time, and Movement Time

Table 29 presents a summary of the statistical results for Total Time, Aiming Time, and Movement Time in the Five Target scenario.

Table 29. Five Target ANOVA Results: Time			
Mask Comparison			
	Total Time	**Aiming Time**	**Movement Time**
Center → Left Low	NS	NS	<0.05
Center → Right Low	<0.05	<0.05	NS
Left Low → Left High	<0.01	<0.05	<0.05
Left High → Right Low	<0.05	NS	NS
Right High → Left Low	NS	<0.05	NS
Right Low → Right High	<0.05	NS	<0.05
Position Comparison			
	Total Time	**Aiming Time**	**Movement Time**
Center → Left Low	<0.05	NS	NS
Center → Right Low	NS	NS	NS
Left Low → Left High	<0.01	<0.05	NS
Left High → Right Low	<0.05	<0.05	<0.05
Right High → Left Low	<0.01	NS	<0.01
Right Low → Right High	<0.01	<0.01	<0.01
Interaction Effects			
	Total Time	**Aiming Time**	**Movement Time**
Center → Left Low	NS	NS	NS
Center → Right Low	NS	NS	NS
Left Low → Left High	NS	NS	NS
Left High → Right Low	NS	NS	NS
Right High → Left Low	<0.01	<0.01	NS
Right Low → Right High	NS	NS	NS

Note: Green cells indicate comparisons that were significantly different
NS = Not Significant

4.3. Weapon Simulator Subjective Rating Results

After completing all shots in a given firing position, the TPs were asked to rate the degree of Interference/Degradation they experienced from the equipment while performing that task using the 5-point rating scale presented in Table 30.

Table 30. Subjective Rating Scale				
No Interference or degradation	Slight Interference; easily worked around	Moderate interference; difficult, but able to work around	Severe interference; very difficult to work around; unacceptable	Extreme interference; unable to work around; unacceptable
1	2	3	4	5

The M40 Mask configuration consistently received the higher mean ratings (indicating more interference/degradation in performance) across all firing positions and in both the One Target and Five Target scenarios (see Figures 37 and 38; error bars represent Standard Deviation).

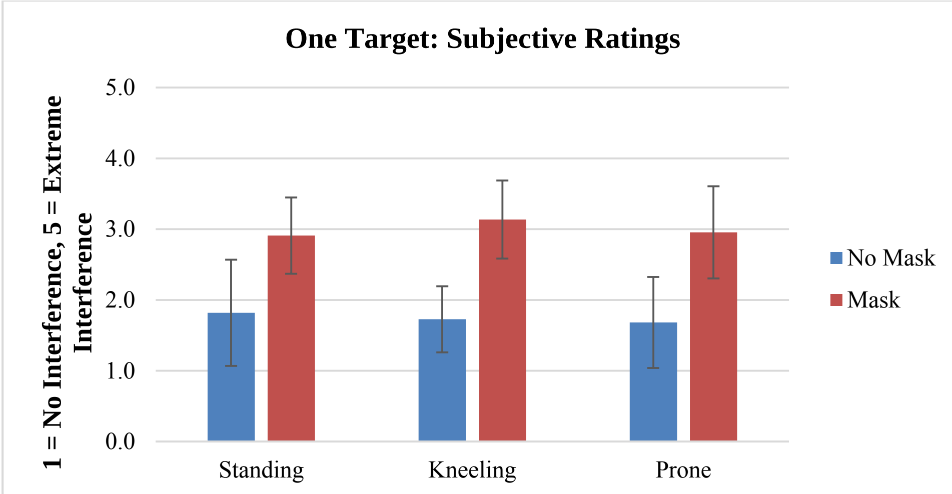

Figure 37. Mean and Standard Deviation of One Target Subjective Rating Results

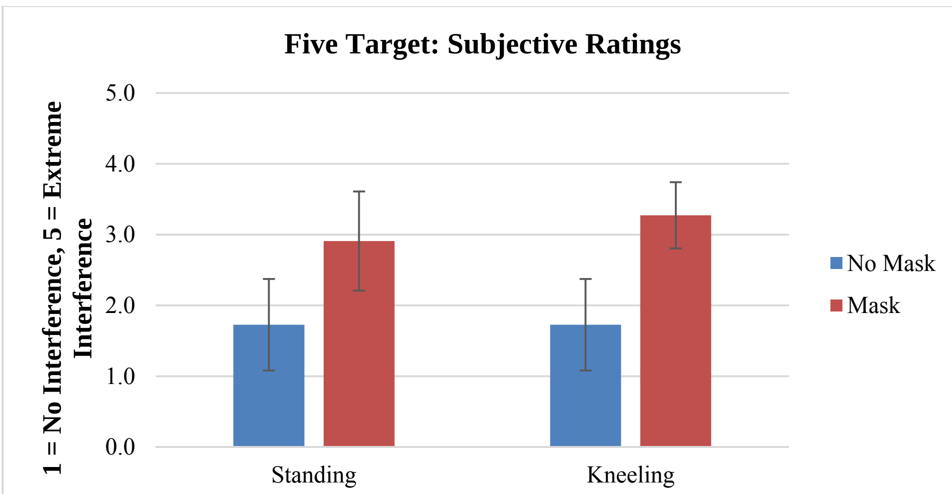

Figure 38. Mean and Standard Deviation of Five Target Subjective Rating Results

The following represents a summary of comments/issues associated with each of the test configurations:

- No Mask Configuration
  - Five TPs (45%) commented that the body armor slightly interfered with proper buttstock placement in the Standing Unsupported firing position. They would ideally like to place the buttstock in the pocket of their shoulder just under the collar bone, but the shoulder strap of the plate carrier covered this location. This made it slightly more difficult to shoot accurately than when wearing no armor at all; however, all of the TPs also commented that they train regularly wearing body armor and are used to compensating for this restriction.
  - Two TPs (18%) commented that the shoulder strap of the body armor slightly interfered with proper buttstock placement in the Kneeling Unsupported firing position; however, the other nine TPs commented that their equipment/kit did not

interfere because the Kneeling Unsupported firing position was more stable, and they were better able to support the weapon.

  - Four TPs (36%) commented that their body armor and the equipment mounted on the front of their body armor raised their body off the ground when in the Prone Unsupported firing position. This made engaging the target more difficult, because they could not rest the magazine of the weapon on the ground and had to raise up on their elbows. This is a more difficult/less stable position to hold than when resting the magazine on the ground.
  - Two TPs (18%) also commented that they could not raise their head as high as they would have liked in the Prone Unsupported firing position because their helmet contacted the back of their body armor.

- M40 Mask Configuration
  - The biggest problem with shooting with the M40 Mask, reported by all TPs, was that the mask prevented the TPs from achieving the proper angle/sight picture with the ACOG sight. They had to either turn their head further (almost laying it sideways) or cant/tilt the weapon in order to see through the sight. Both of these positions were more difficult to hold steady for an extended period of time, and were more time consuming when transitioning between targets.
  - All of the TPs reported the ACOG sight appeared blurry when looking through the lens of the mask, even when the mask was not foggy.
    - Two TPs also commented that fogging became an issue, obscuring their vision and making it difficult to see the reticle.
  - Seven TPs (64%) commented that the M40 mask limited their field of view, which made transitioning between targets more time consuming. When transitioning between targets they typically locate the next target with their eyes, and then bring the weapon and the rest of their body to the target, without lowering the weapon. With the M40 mask they could not see the next target without turning their entire head, which also required them to lower the weapon, locate the next target, and then raise the weapon and re-set into a stable firing position. They felt this process was much more time consuming than when not wearing the M40 mask.

4.4. <u>Weapon Simulator Discussion</u>

4.4.1. <u>Mask Configuration Comparison</u>

While the main effect of mask configuration was not significant, mean B-Distance values for the no mask configuration were lower (indicating better shooting performance: shots closer to the center of the target) than mean values when wearing the M40 CB mask in both the One Target and Five Target scenarios.

TPs performed about the same in terms of E-Distance in both the No Mask and M40 Mask configurations in both the One Target and Five Target scenarios.

For all movement arcs, TPs posted higher Total Time, Aiming Time, and Movement Time values in the M40 Mask configuration than in the No Mask configuration.

All of the TPs reported that the biggest problem with shooting with the M40 Mask was that the mask made it difficult for the TPs to achieve the proper angle/sight picture with the ACOG sight. They had to either turn their head further (almost laying it sideways) or cant/tilt the weapon in order to see through the sight. Once they were able to achieve this position, they were able to accurately engage targets with slight decrements in accuracy – as shown by the similar E-Distance values for both the No Mask and M40 Mask configurations.

However, it is possible that the eye piece of the M40 mask affected their eye relief, and resulted in slightly lower B-Distance values (shots hitting farther away from the center of the target) in the M40 Mask configuration. The B-Distance values depend on a consistent sight picture and accurate zero, and if the shooter changes their eye relief (relative to the sight) the accuracy of the shots will be affected. The shooter will think they are aiming at the center of the target, when in fact the barrel is aligned slightly off-center. Unlike B-Distance, the E-Distance value will not be affected by a change in eye relief, provided the same sight picture is maintained throughout the 5-shot series.

While the TPs were able to perform similarly in terms of B-Distance and E-Distance after tilting their head or canting the weapon to one side, all of the TPs reported that these positions were more difficult to hold steady for an extended period of time, and were more time consuming to assume when transitioning between targets.

Seven TPs (64%) also commented that the M40 mask limited their field of view, which made transitioning between targets more time consuming. This is reflected in the statistically significant differences in the time variables noted above.

It is believed that the significant differences in terms of Total Time and Movement Time were due to the mask restricting the field of view of the TPs, which made it more difficult/time consuming to locate the next target and align the sights with the target. The mask also interferes with the mechanics of aiming, making achieving proper eye relief and a proper cheek to stock weld more difficult.

The Aiming Time variable represents the time the weapon was pointed at the target prior to pulling the trigger. This equates to the time the TPs spent fine tuning their sight picture prior to pulling the trigger. The significantly longer aiming times in the M40 Mask configuration (as compared to the No Mask configuration) indicate that the mask made it more difficult/time consuming for the TPs to achieve a proper sight picture and decide to pull the trigger.

4.4.2. Firing Position Comparison

Firing position also had a significant effect on marksmanship performance. For the One Target scenario, E-Distance (shot group tightness) in the Prone Unsupported firing position was significantly smaller (indicating better performance: tighter shot groupings) than in the Kneeling Unsupported or Standing Unsupported firing position, and E-Distance values in the Kneeling

Unsupported firing position were also significantly smaller than in the Standing Unsupported firing position.

For the Five Target scenario, B-Distance (accuracy) values for the Kneeling Unsupported firing position were significantly lower (indicating better performance: shots were closer to the center of the target) than in the Standing Unsupported firing position for both the Center target location and the Right Low target location. B-Distance values were also lower in the Kneeling Unsupported firing position than in the Standing Unsupported firing position for the other target locations, with the exception of the Right High target location; however, they did not significantly differ.

E-Distance (shot group tightness) values for the Five Target scenario were consistently higher (indicating worse performance: shot groupings were larger) in the Standing Unsupported firing position than in the Kneeling Unsupported firing position, but only significantly differed for the Left High target.

The TPs were also significantly slower in the Kneeling Unsupported firing position than in the Standing Unsupported firing position when transitioning between targets in terms of Total Time, Aiming Time, and/or Movement Time for all movement arcs.

These results are to be expected, as the Standing, Kneeling, and Prone Unsupported firing positions progressively become more stable. In unsupported firing positions, the arms are largely responsible for holding the weapon steady. The positioning of the arms can be divided into muscular and skeletal positioning. Muscular positioning requires effort to keep the arms in a given position, skeletal positioning allows the forces to be transferred through the bones, minimizing the effort required to keep the arms in that position.

In the Standing Unsupported firing position, the shooter must stabilize the weapon using mostly muscular positioning. In the Kneeling Unsupported firing position, additional skeletal positioning can be used by resting the non-firing arm on the raised knee, resulting in a more stable position. In the Prone Unsupported firing position, the shooter has a wider base of support and can rest both arms on the ground, providing the most stable position (compared to Standing and Kneeling). This stability translates into more accurate and consistent shot placement (i.e. lower B-Distance and E-Distance values for more stable firing positions).

In turn, while the Standing Unsupported firing position is less stable than the Kneeling or Prone firing positions, it is a more dynamic position which can be assumed more quickly than the Kneeling Unsupported firing position. It is easier and faster to both turn the body and reposition the feet when standing than when kneeling.

5. 75 m Stand Alone Target Results

In order to directly compare results from the weapon simulator to results from the live fire range (within the limitations in terms of target placement discussed above in Chapter 1), a side-bar assessment was conducted using a single E-type silhouette. This silhouette was set up on the live fire range, 75 m directly in front of the shooter, and remained visible for the entire session (i.e., the target did not "pop-up"). The TPs fired two series of five shots in the Standing Unsupported, Kneeling Unsupported, and Prone Unsupported firing position, all in the No Mask configuration. This data was compared to results from the weapon simulator in the One Target scenario using a paired samples t-test. (Note: TPs 1 and 2 did not complete the Prone Unsupported trial on the live fire range for the 75 m stand-alone target).

5.1. 75 m Stand Alone Target: B-Distance

As shown in Table 31 and Figure 39, B-Distance values were significantly lower (indicating better performance: shots closer to the center of the target) with the weapon simulator than on the live fire range in the Standing Unsupported and Kneeling Unsupported firing positions, $p < 0.05$. B-Distance and E-Distance values also tended to be lower with the weapon simulator in the Prone Unsupported firing position; however, the differences were not significant, $p > 0.05$.

Table 31. B-Distance Results: 75 m Target Comparison

		Mean (mm)	Mean Difference (mm)	N	Std. Deviation	Std. Error Mean	t	df	Significance (2 - tailed)
Standing	Live Fire	205.82	76.22	11.00	36.77	11.09	7.26	10.00	<0.01
	Simulator	129.60		11.00	36.04	10.87			
Kneeling	Live Fire	203.69	97.19	11.00	67.41	20.32	4.63	10.00	<0.01
	Simulator	106.51		11.00	33.12	9.98			
Prone	Live Fire	165.91	62.93	9.00	90.07	30.02	1.53	8.00	0.16
	Simulator	102.98		9.00	51.45	17.15			

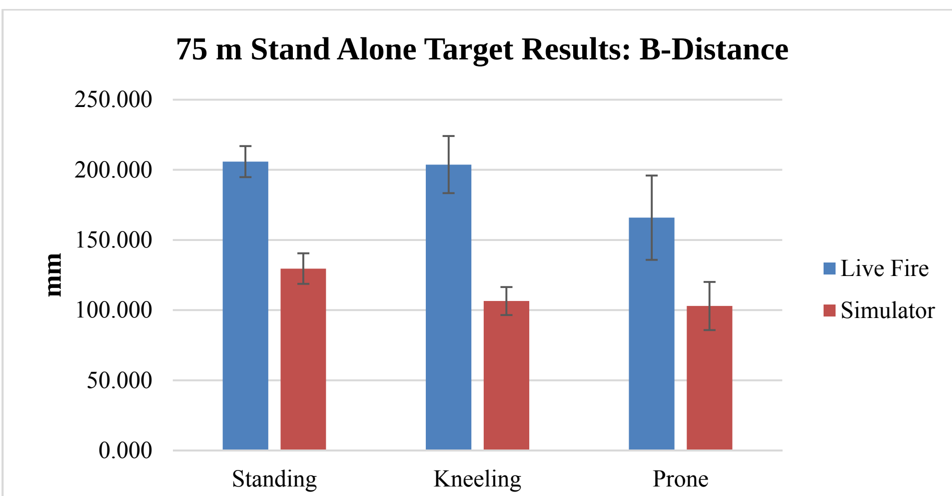

Figure 39. Mean and Standard Error of 75 m Stand Alone Target Comparison: B-Distance

5.2. 75 m Stand Alone Target: E-Distance

As shown in Table 32 and Figure 40, E-Distance values were significantly lower (indicating better performance: shots in tighter groups) with the weapon simulator than on the live fire range in the Standing Unsupported and Kneeling Unsupported firing positions, $p < 0.05$. E-Distance values also tended to be lower with the weapon simulator in the Prone Unsupported firing position; however, the differences were not significant, $p > 0.05$.

Table 32. E-Distance Results: 75 m Target Comparison

		Mean	Mean Difference	N	Std. Deviation	Std. Error Mean	t	df	Significance (2 - tailed)
Standing	Live Fire	136.01	48.34	11.00	26.55	8.01	6.31	10	<0.01
	Simulator	87.67		11.00	23.34	7.04			
Kneeling	Live Fire	103.48	38.62	11.00	16.74	5.05	5.95	10	<0.01
	Simulator	64.86		11.00	26.89	8.11			
Prone	Live Fire	57.33	11.06	9.00	16.07	5.36	1.46	8	0.18
	Simulator	46.26		9.00	17.28	5.76			

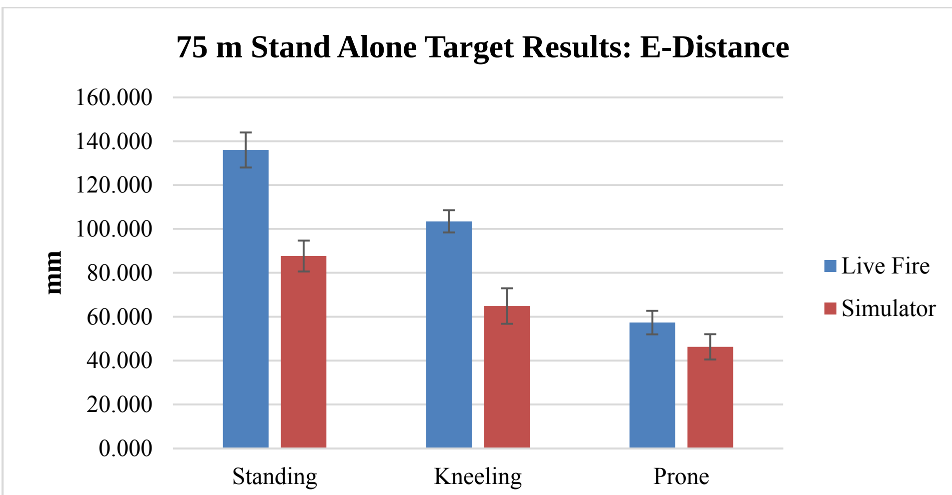

Figure 40. Mean and Standard Error of 75 m Stand Alone Target Comparison: E-Distance

5.3. 75 m Stand Alone Target Discussion

For both B-Distance (accuracy) and E-Distance (shot group tightness) the TPs performed better (i.e., shots closer to the center of the target and in tighter groups) with the weapon simulator than on the live fire range in the Standing Unsupported and Kneeling Unsupported firing positions. In the Prone Unsupported firing position the same trend was observed, but the differences were not significant.

There are several possible explanations for these significant differences. One potential confound, which was not identified until after the data collection was concluded, was that the appearance of the target was not identical between the weapon simulator and the live fire range. The live fire range used an olive drab E-type silhouette with no markings (the entire target was the same color), while the weapon simulator used a paper target with a black E-type silhouette target and a white center (see Figure 41). It is possible that the TPs were able to fire tighter groups that were closer to the center of the target on the weapon simulator because they had a clear target to aim for, while the Olive Drab target on the live fire range did not provide a clear center point to aim for.

a)  b) 

Figure 41. Image on the left (a) shows the Olive Drab "E" Type Silhouette Targets used on the live fire range, image on the right (b) shows the paper target used for the weapon simulator.

However, other studies have also found significant differences between live fire and weapon simulator results. This study supports the findings of Scribner et al. (2007) which found significantly lower radial error (analogous to B-Distance) for the simulator condition as compared to performance on a live fire range.

One possible explanation for the significant differences between the weapon simulator and the live fire range is the additional recoil forces and the psychological effects associated with firing live rounds. The recoil force or "kick" of the weapon is greater when firing a live round than the force imparted by the CO2 recoil simulation system used with the weapon simulator. This additional recoil may have made it more difficult for the TPs to fire accurate shots as the barrel of the weapon may rise higher and the buttstock of the weapon may slide around in the shoulder pocket more in between shots.

Aside from the force of the recoil, the noise and flash associated with firing live rounds can cause some shooters to flinch in anticipation of the shot, and negatively impact accuracy. It is possible that the lower audible noise and lack of a muzzle flash when firing the simulator weapon resulted in the TPs avoiding this flinch reflex and resulted in more accurate performance.

It is also possible that subtle changes in outdoor atmospheric conditions such as changing wind velocities, barometric pressures, and ambient temperatures may contribute to larger ballistic error in live fire performance.

6. Discussion: Weapon Simulator vs. Live Fire Comparison

While the results of the 75 m stand-alone target indicate that TPs performed better on the weapon simulator than on the live fire range in terms of B-Distance and E-Distance, the overall results of the weapon simulator test methodology and the live fire test methodology showed similar trends.

There were no significant differences between the No Mask and M40 Mask configurations in terms of shot accuracy in both the live fire and weapon simulator results. Both test methodologies showed the TPs performed slightly better (i.e., shots closer to the center of the target) in the No Mask configuration, but these differences were not statistically significant.

Both test methodologies also found significant main effects for firing position. On the live fire range, the Prone Unsupported firing position showed a significantly higher hit rate than the Standing or Kneeling Unsupported firing positions, and showed a general trend where the Standing, Kneeling, and Prone Unsupported firing positions progressively become more accurate. These same trends were observed on the weapon simulator, with statistically significant differences for B-Distance and E-Distance found between firing positions.

The main difference in the results, as relates to evaluating the effect of equipment on marksmanship performance, is that the weapon simulator results revealed a significant difference in time to transition between targets, whereas no significant differences in engagement time were found in the live fire results.

7. Conclusions

As noted in Chapter 1, the weapon simulator test methodology described in this report is not intended to replace live-fire evaluations, but the use of a weapon simulator has some advantages over live-fire evaluations, particularly for early evaluations of developmental items. During this evaluation, the weapon simulator and live fire test methodologies were both able to capture similar trends regarding the impact of the M40 Mask on marksmanship performance.

In addition, while the live fire test methodology did not find any significant differences between the M40 Mask and No Mask configurations, the weapon simulator data shows the TPs were significantly slower when transitioning between targets while wearing the M40 mask. This difference is believed to be due to the difference in movement angle for the weapon simulator test methodology (i.e., TPs were required to move through a 50° arc on the weapon simulator to transition between targets, compared to a 3.5°-7° arc on the live fire range), and not an inherent difference in performance with a weapon simulator. If the live fire range presented targets at greater angles relative to the shooter, it is believed the same results would be observed (i.e., it would take significantly longer to locate and engage a target in the M40 Mask configuration than in the No Mask configuration).

This finding illustrates one of the advantages to a weapon simulator, namely that the simulator has more flexibility regarding target locations and thus can create scenarios that stress equipment to a greater extent (i.e., greater distances/angles between targets and high angle targets). The live fire range is somewhat limited in target presentation locations based on safety concerns and established firing lanes.

Also during this evaluation, subjective ratings and comments were collected, which enabled conclusions to be drawn regarding the reasons the M40 Mask configuration affected marksmanship performance (i.e. the M40 mask limited their field of view, which made transitioning between targets more time consuming).

The results of the 75 m stand-alone target indicate that marksmanship performance on a weapon simulator may not be identical to the performance on the live fire range. Specifically, the TPs performed significantly better (tighter shot groups, closer to the center of the target) with the weapon simulator than with the live fire range. However, both the weapon simulator and the live fire range data showed the same trends. For example, in the Standing Unsupported firing position, TPs performed significantly better with the weapon simulator than on the live fire range, but in both the live fire condition and the simulated condition Standing Unsupported was significantly larger than the Kneeling and Prone Unsupported firing positions in terms of E-Distance.

These similar trends indicate that the weapon simulator test methodology can effectively be used to evaluate equipment, because the results of the weapon simulator (as it relates to the effects of the M40 CB mask on marksmanship performance) mirror those which would be captured in a live fire evaluation.

This document reports research undertaken at the U.S. Army Natick Soldier Research, Development and Engineering Center, Natick, MA, and has been assigned No. NATICK/TR- 16/021 in a series of reports approved for publication.

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APPENDIX. Demographic Data Summary

Subject No.	Last time Qualified with assault weapon (Month, Year)	Weapon	Current level Qualification as rifleman (#1)	Qual Prior to current (#2)	Shooter handedness	Eye to aim weapon	Corrective glasses or contacts	Used Optical or Thermal Sights	If yes, device type
1	11, 2013	M4/M16	Expert	Sharpshooter	Right	Right	Yes	Yes	AN/PVS-30
2	8, 2014	M4/M16	Expert	Expert	Right	Right	No	No	
3	11, 2013	M4/M16	Expert	Sharpshooter	Right	Right	Yes	Yes	AN/PVS-30
4	8, 2014	M4/M16	Expert	Expert	Right	Right	No	Yes	PVS-29, MTM, ELLAN, EOTECH, ACOG, PVS-15,
5	3, 2014	M4/M16	Expert	Expert	Right	Right	No	Yes	PAS-E13E, ELCAN, EOTECH, PVS-17
6	2, 2014	M4/M16	Expert	Expert	Right	Right	Yes	Yes	
7	2, 2014	M4/M16	Expert	Expert	Left	Left	No	Yes	ACOG, ELCAN, EOTECH, M68
8	2, 2013	M4/M16	Expert	Sharpshooter	Right	Right	No	Yes	EOTECH, LLAN, M68
9	2, 2014	M4/M16	Expert	Expert	Right	Right	No	Yes	ACOG, L-LAN, EOTECH, X3 Multiplier, Doc sight
10	8, 2014	M4/M16	Sharpshooter	Sharpshooter	Right	Right	No	Yes	ACOG, CCO, ITAS (TOW)
11	8, 2011	M4/M16	Expert	Expert	Right	Right	Yes	Yes	ACOG, CCO, LEOPOL, NIKON